METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER)

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Subscription Rates throughout the World - - 24/- per annum, Post free

Published monthly by THE KENNEDY PRESS, LIMITED.

REGISTERED OFFICE: 21, Albion Street, Manchester, 1.
Telephone: Central 0098. *Telegrams:* "Kenpred," Manchester.

LONDON OFFICE: Bedford Street, W.C. 2.
Telephone: Temple Bar 2629.

MALICE *in* BLUNDERLAND

"Its a wicked waste'" exclaimed Mr. Walrus, looking at a handful of small cutting tools which Alice had just returned to the stores. "These were all brand new on Monday. Careless treatment, I'll be bound."

"Speaking of treatment," murmured the Mad Hatter, "they do say—"

"Waste of time I Waste of labour," said Mr. Walrus, who was in no mood to listen to anything but the sound of his own voice. "Waste, waste, waste," he repeated more to himself than to the others.

"They do say," ventured the Hatter once more, "that is, if I might make the suggestion—"

"Well?" asked Mr. Walrus, breathing heavily through his whiskers, and beating a tattoo on his teeth with a drill, "And what DO they say?"

"That MACROME TOOLS can save a lot of trouble—a lot of time, and a lot of waste."

"AND a lot of bad temper," added Alice reproachfully.

The Hatter was not so mad after all. MACROME TOOLS CAN show you the way to increased production and reduced labour. Send NOW for catalogues and informative literature.

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METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER."

FEBRUARY, 1945 VOL. XXXI. No. 184

A Century of Aluminium

ALTHOUGH the first step towards the production of aluminium was made by the Danish physicist, Oerstedt, in 1825, when he obtained aluminium chloride, it was two years later that Wöhler successfully isolated the metal. The small globules then obtained were much contaminated by other substances and it was not until 1845 that Wöhler produced pure metal in sufficient quantity to carry out physical tests. For all practical purposes, therefore, it appears reasonable to assume that 1945 can be regarded as the century year of aluminium and, to celebrate the occasion, this issue gives a brief outline of the history and development of the metal. Particular attention has been given to recent developments in the foundry, to the production and use of sheet and strip, to the equipment and production of forgings and stampings, and to die-casting. A consideration of the developments connected with the extrusion of aluminium and its alloys has unavoidably been omitted from this issue, but this aspect of development in the industry will be discussed in a later issue.

As will be noted elsewhere in this issue, aluminium was regarded as a laboratory curiosity for a number of years, but, in 1854, Sainte-Claire Deville invented a process of extraction by which the cost of production was greatly reduced, but at 16s. per lb. it is not surprising the industrial applications continued to be very slow. Thirty years later, however, Hall, in the United States, and his contemporary in Europe, Héroult, opened a new era for aluminium by their work on the electrolytic production of the metal from alumina dissolved with cryolite. By 1905, world production reached 10,000 tons per annum, and in 1936, consumption was estimated at over 400,000 tons. To satisfy the increased peace-time demands for the metal consumption continued to grow at a rapid rate until the opening of hostilities in 1939. On the outbreak of war the need for aircraft became acute and to ensure an adequate supply of aluminium for this purpose, supplies of the metal produced were controlled and applied almost wholly for war purposes. During the war period production of the metal has continued to grow at a phenomenal rate and when world production figures during this period become available, it is probable that even those in the industry will be astounded.

It will be noted that the major contributions to the great progress achieved have occurred during the last fifty or sixty years. The development of the motor-car and later the aeroplane have been largely responsible for the increased demand for this metal, but it was the continued metallurgical development and improved technique in manufacturing operations that enabled the metal to meet the needs of the designer and engineer. While aluminium itself has many uses, the progress achieved is largely due to the fact that it unites readily with a number of other metals to form useful alloys. One or several elements may be added to aluminium and, in consequence, a large number of aluminium alloys have been developed, some of which are used without heat-treatment, while others depend upon some form of heat-treatment for improvement in their physical properties.

An outstanding property of aluminium is its low density, thus, a given piece of equipment, when made in aluminium instead of ferrous or copper alloys, is much lighter. The development of alloys, while retaining the advantage of low density, has added greatly to the strength, and on a weight/strength ratio the alloys are comparable with steel. This light weight makes aluminium alloys particularly suitable for transporting equipment, whether for rail or road vehicles, for ships, and for containers used to transport products. In addition to low density, however, aluminium and its alloys possess high thermal and electrical conductivity. For this reason they may be used advantageously for heat exchangers, cooling coil fins, and in any equipment where efficient heat transfer, uniform distribution of heat, and the avoidance of local overheating are important. The high electrical conductivity makes aluminium well suited for the construction of bus-bars, cables and other electrical conductors. The low modulus of elasticity and the high plasticity enable aluminium equipment to withstand excessive accidental overloads by extensive deformation, whereas a less ductile material would suffer local failure. Another valuable attribute is the high thermal reflectivity of aluminium.

Apart from low density, however, an outstanding property is the stability of aluminium in contact with many other materials. Considering how high aluminium stands in the electromotive series it is surprising how many materials are substantially inert to it. Mention may be made of distilled water, steam, hydrogen peroxide, concentrated nitric acid, sulphur, hydrogen sulphide, organic sulphur compounds, anhydrous sulphur dioxide, acetic acid, fruit acids, fatty acids, sodium soap, ammonia, aldehydes, turpentine, alcohol, varnish, many dye solutions, beer and milk, which have been handled advantageously in aluminium equipment. This remarkable stability is attributable to a very thin adherent protective coating of aluminium oxide which forms spontaneously on the surfaces which are exposed to air or even to liquids containing dissolved oxygen or water. Where the conditions under which the

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

aluminium is being used prevents the oxide film forming spontaneously, a thicker, more protective, much more abrasion-resistant film may be formed on aluminium by suitable anodic oxidation processes.

For these latter applications commercially pure aluminium or the alumirium-manganese alloy, contain-in about 1·25% manganese, are generally used. These materials are readily formed and welded, and much experience has been accumulated in their fabrication and use. These materials have only moderate strength and may be inadequate to carry the loads required. Thus, for many purposes stronger alloys must be used. As a general rule, however, the resistance of aluminium to attack by chemicals increases as the purity of the aluminium increases and in order to obtain high strength together with maximum corrosion resistance Alclad sheet or strip may be used.

Even from this brief survey it will be appreciated that aluminium possesses a combination of chemical and physical properties which fit it admirably for a multiplicity of services. Higher efficiency, higher quality of product, and lower operating or transportation costs are among the advantages to be gained by the intelligent use of this metal. As mentioned earlier, during the first four years of the war the use of aluminium had to be restricted almost entirely to military applications, predominantly aircraft. Even for this purpose substitutes had to be adopted to conserve supplies. During the past year it has been possible to make it freely available for other military purposes, while still meeting the needs of aircraft programmes. The stage has now been reached where aluminium can once again be released to manufacturers for civilian production.

Institution of Metallurgists

THE formation of a professional body representative of metallurgists in all branches has been under discussion for some time. In view of the demand for action in this direction a group of well-known and recognised metallurgists has taken the initiative in forming a professional "Institution of Metallurgists," and a preliminary announcement of this proposed body has been made.

The Institution will be registered as a company limited by guarantee. The Memorandum of Articles of Association has been drawn up and will be published as soon as they have been approved by the Board of Trade. Applications for membership will then be invited. One of the main objects included reads :—

"To promote in every possible way the interests of and to maintain and increase the status and prestige of metallurgists and to encourage scientists whose main interests lie in metallurgy to become metallurgists and designate themselves to metallurgy."

Power is also taken to advance the study of metallurgy, to promote the better education of metallurgists to maintain a register of qualified members, to adopt any lawful means conducive to the setting up and maintenance of a high standard of professional conduct amongst metallurgists and to collaborate with existing professional and scientific institutions.

We have no doubt that this proposal will meet with an immediate response from metallurgists throughout the country and that a progressive and powerful Institution will be formed. Correspondence on the subject should be addressed to Institution of Metallurgists, 4, Grosvenor Gardens, London, S.W.1.

The Structural Industry and War

LITTLE attention has been given to the contribution made by British structural engineers to the war effort. Probably this has been due to the secrecy associated with much of the work carried, but reference can now be made to some work carried out at almost a moment's notice to complete a vital part of the invasion harbours. Construction of the "whale" or pierhead equipment had been a military responsibility. In April last year it was decided to call upon civilian personnel to ensure speedy completion, for without the "whales" the usefulness of the piers would have been reduced.

The authorities asked Messrs. Dorman Long and Co., Ltd., to undertake co-ordination of the work. It was a tremendous task, and the key to satisfactory launching of the immense invasion project. The whole of the company's resources was immediately made available with Mr. C. Hipwell, manager of the firm's London Constructional Department, in charge of the work. Fifteen pierheads had to be dealt with in one month.

By a fortunate chance, the annual meeting of the British Structural Iron Association, representing the whole trade, was to be held in London the next day. An appeal to the trade was made in person by the Assistant Director General of the Ministry of Supply. The response was immediate, and within 24 hours of the approach to Dorman Long and Co. the whole of the fabricators in the country had made detailed offers of assistance. A selection giving the necessary balance of manpower was made, and a few hours later skilled fabricators and others were travelling from Yorkshire, Scotland, the Midlands and other parts of the country to Southampton.

The "whales" were being built in Wales, on the East Coast and the West Coast of Scotland, and had to be towed by the Navy round to Southampton. One or two of them were already on the way when Dorman Long were asked to take over co-ordination of the work. The vessels were 150 ft. long by 60 ft. wide, and in addition to certain work remaining to be done on all of them, some had to receive special treatment. On each of the latter 30 tons of steel brackets had to be ranged along the sides from which 300 tons of concrete blocks were hung as additional protection. This type of vessel also required overhead ramp structures involving 30 tons of structural steelwork. Other vessels needed the addition of large attachments to take buffer pontoons.

Until the vessels arrived it was not known how much work each required, and some of them, in addition to deficiencies, sustained damage during the long tow, and this also had to be rectified. On one vessel alone nearly two miles of welding was done on arrival at Southampton. The work went on day and night without interruption, and 15 vessels were ready for service before the due date.

An atmosphere of urgency characterised those days on the South Coast; on each vessel was displayed prominently the time when the work had to be completed. There was tremendous enthusiasm in carrying out the work, and in every case the job was done before the time specified. It was a great achievement by the British structural industry, and a tribute to the resources and experience of Mr. Hipwell and his company that they were asked to co-ordinate this work at a critical stage in the preparations for invasion.

Sub-Zero Treatment of Steels

By H. C. Amtsberg

Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Large numbers of reports and several articles have been written on the improved properties and performance brought about by sub-zero cooling of steel parts, particularly tools. Claims of several hundred per cent. improvement in life, while probably exaggerated, are not uncommon. In other cases, the treatment was a partial cure for improper initial heat-treatment. Nevertheless, the value of the process is unquestioned. It is likely to become a routine part of normal heat-treating practices and sufficient authoritative information is already in evidence to warrant a vigorous programme of actual exploitation in the shop and further study in the laboratory. It appears, therefore, that a presentation of the fundamentals of cooling hardened steels to temperatures considerably below room temperature properly correlated with the basic treatment cycle and related structural changes is in order.

WHEN steel is heated to its hardening temperature, the structure consists of a solid solution of carbon in iron, known as austenite, with or without alloying elements in solution, and with or without free iron or alloy carbides, depending on the composition and temperature. Austenite is relatively soft, tough and ductile, even at room temperature. The carbides are very hard compounds of carbon and iron or alloying elements such as chromium, tungsten, molybdenum, and vanadium. When hardening such steel by cooling in some suitable medium, the austenite transforms to martensite, a hard and strong constituent that is an aggregate of finely dispersed carbides in iron. This aggregate bears one similarity to suspensions such as colloidal graphite in water except that the particle size in the former is much finer.

As explained in greater detail later, an ideal hardening operation would be one in which all of the austenite was transformed to martensite upon reaching room temperature. This is true even if the final hardness desired is much lower than would result from this ideal hardening, for it is well known that the best physical properties are obtained by quenching (i.e., water, oil, or air) to maximum hardness, then tempering to the desired combination of hardness and strength versus ductility and toughness.

In many steels, however, the transformation of the soft high-temperature constituent austenite to the hard constituent martensite does not always go to completion. In other words, after the steel has been cooled to room temperature some austenite has still been retained. This is illustrated in Fig. 1 showing isothermal time temperature transformation curves of a high-speed steel determined by Gordon, Cohen, and Rose[1] and an air hardening die steel by Payson and Klein[2] on which cooling curves for standard treatments have been superimposed.* In Fig. 1 (*a*), it is seen that oil quenching 18-4-1 high-speed steel to room temperature transforms only about 75% of the structure to martensite while 25% remains as untransformed austenite. Fig. 1 (*b*) shows that about 5% of austenite remains in the chromium air-hardening steel after cooling in air to room temperature. Many other steels retain austenite in a similar manner provided the cooling is sufficiently rapid to prevent transformation at a high temperature to a relatively soft product—pearlite. The cooling rates of the steels in Fig. 1 could be reversed and the amount of austenite retained in each case would be approximately the same.

* For a fundamental discussion on isothermal transformation curves, the reader is referred to the work of Davenport (3) and Greninger and Troiano (4).

1 Paul Gordon, Morris Cohen and Robert S. Rose, "The Kinetics of Austenite Decomposition in High-Speed Steel." *Am. Soc. Metals*, **31**, 1943, pp. 161–197.

2 P. Payson and J. L. Klein, "The Hardening of Tool Steels." *Am. Soc. Metals*, **31**, 1943, pp. 218–244.

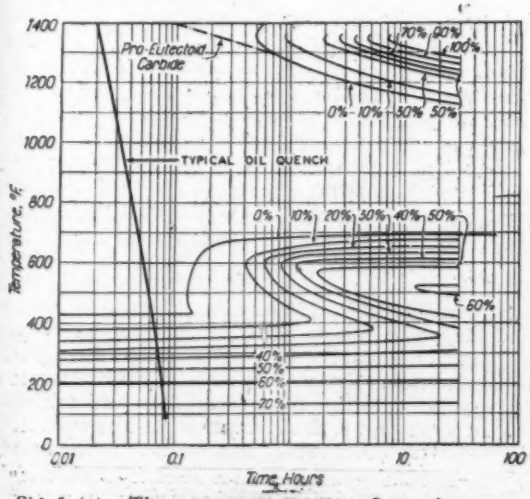


Fig. 1 (a).—Time-temperature transformation curve for 18–4–1 high-speed steel.

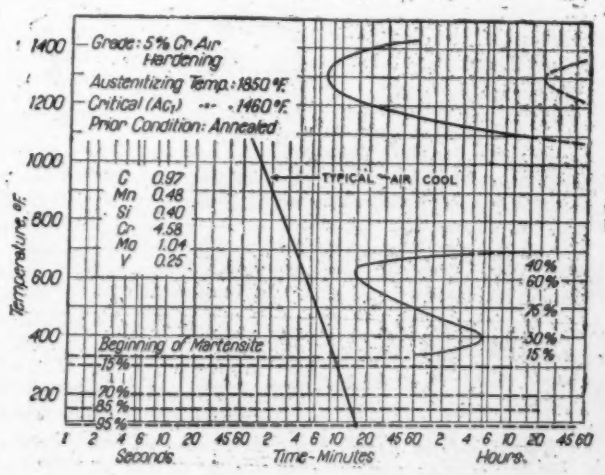


Fig. 1 (b).—Time-temperature transformation curve for 5% chromium air-hardening steel.

Furthermore, K. Honda and K. Iwase[5] have shown that more austenite *may* be retained by oil quenching than by water quenching, probably due to the greater degree of thermal stress in the latter. It is further believed that the same phenomenon exists in higher alloy steels when air- and oil-quenched, respectively. It is impossible to state a specific rule, but it may be *generally* said, that the higher the carbon and alloy content and the higher the hardening temperature, the greater will be the tendency to retain austenite. Thus, it is apparent that mixed structures of this nature may be present frequently in "as quenched" steel.

Retained austenite can be made to transform in a number of ways. In a few steels, in which the amounts of retained austenite are relatively small, a sufficient length of time (sometimes months or years) at room temperature will change all or nearly all of it to martensite. This, of course, is frequently disadvantageous, particularly for dies and gauges, because full hardness and dimensional stability are not obtained at once. This explains the inability of many gauges to maintain shape and size accurately over a long period of time. In all steels, the austenite can be transformed by tempering, but frequently such high temperatures are required as to lose hardness of the martensite and cause transformation of the austenite to a softer produce—bainite. By again referring to Fig. 1, it is obvious that this purpose may be accomplished by simply continuing cooling of the steel to considerably below room temperature. Gordon and Cohen[6] have shown how such treatment reduces the stability of the retained austenite, that is, reduces its reluctance to transform. In many plain carbon and low alloy steels, either medium or high carbon (including carburised), one such cooling to a temperature of — 100° F. is sufficient to virtually complete all transformation. In other steels, particularly the highly alloyed die steels, several such operations may be necessary with intermediate tempering between each sub-zero treatment. Indeed, high-speed steel must be tempered in the conventional manner at least once during the heat treatment cycle in order to obtain transformation of all of the austenite.

Now that it has been determined how an austenite-free structure may be obtained, is it worth while to go to all this trouble? It is well known that, from the mechanical property standpoint, the amounts of retained austenite and untempered martensite should be at an absolute minimm in the final product. Repeated tests by Cohen and his co-workers[6, 7] have indicated higher strength and toughness without appreciable loss in hardness when all the austenite has been transformed by tempering or sub-zero treatment, especially the latter, and this is particularly so when the completely transformed structure is followed by a final temper for stress-relief. H. Scott and T. H. Gray† have shown (see Fig. 2) a more than 200% increase in transverse bend strength over a considerable range in hardness by a cyclic treatment after hardening. This consisted of alternately tempering in boiling water and cooling to —100° F. three times followed by the final temper to the desired hardness. Evidence has been offered for high-speed steel, showing that all of the austenite may be transformed by tempering one or more times at the usual temperature (1,050° F.) with cooling to room temperature following each such heating. The amount of austenite that will transform is dependent on the time at the tempering temperature, and the effect on the properties of the progressively reduced amounts resulting thereof, is shown in Table I (from Cohen[8]).

TABLE I.

TEMPERING 18—4—1 HIGH-SPEED STEEL AT 1,050° F.

	Time	Hardness Rockwell C.	Transverse Strength lb./sq. in.	Torsion Impact ft. lb.	Hot Hardness* Rockwell C.
Single Tempering ..	6 min.	65·1	312,000	16	55·0
" " ..	½ hr.	65·7	270,000	30	57·0
" " ..	2½ hrs.	65·0	408,000	48	58·0
" " ..	5 hrs.	64·5	410,000	48	57·0
" " ..	24 hrs.	63·8	——	39	55·0
Double Tempering plus 2½ hrs. ..	2½ hrs.	64·5	454,000	63	57·0

*Hot Hardness measured at 1,000° F.

The effect of these improved properties has been substantiated by actual shop results where reduced breakage and edge chipping, longer cutting life, and more blanks per grind have all been obtained.

As previously pointed out, it is usually desirable to have the transformation take place at relatively low temperatures (under 300° F.) This necessitates a note of caution, since steels containing considerable proportions of austenite are provided with a "cushion" of high plasticity for accommodation of considerable stress. If this "cushion" is removed, particularly at very low temperatures where plasticity in general is quite low, stresses resulting from natural dimensional changes occur which connotes a serious cracking hazard. With these facts in mind then, an approach to practical application of sub-zero treatments can be made.

For carbon or moderately alloyed steels of medium carbon content such as SAE 1,045, 4,140, 4,340 and NE equivalents, the practical value of sub-zero cooling is questionable because the amounts of retained austenite are either nil or relatively small. Furthermore, in most engineering applications of steels of this type, tempering temperatures are fairly high and hardness considerably reduced, wherein the conversion of the austenite to bainite would not be objectionable. Bainite, untempered or tempered, is known to have excellent properties for applications not requiring maximum hardness.

On water- and oil-hardening tool steels, alloy carburising steels, and other low-alloy high-carbon steels such as S A E 52,100, the treatment has been found frequently beneficial. Typical cycles are illustrated in Fig. 3. In general, cycle (*a*) is satisfactory for virtually all alloy carburising steels and, in some cases, the other steels as well. Cycles (*b*) and (*c*) offer considerably reduced danger of cracking, particularly where sharp corners or edges are present or where the part has hardened throughout the cross-section. Cycle (*c*) is especially advantageous for gauges since it offers the greatest degree of stabilisation. In all cases, the final temper is the last operation and this is true of all subsequent treatments discussed.

†Metallurgical Section Engineer and Consulting Metallurgical Staff respectively, Westinghouse Research Laboratories.

3 Edmund S. Davenport, "Isothermal Transformation in Steels." *Am. Soc. Metals*, **27**, 1939, pp. 837–886.

4 A. B. Greninger and A. R. Troiane, "Kinetics of the Austenite to Martensite Transformation in Steel." *Am. Soc. Metals*, **28**, 1940, pp. 537–574.

5 K. Honda and K. Iwase, "On the Transformation of Retained Austenite into Martensite by Stress." *Am. Soc. Steel Treating*, **11**, 1927, pp. 399–412.

6 Paul Gordon and MorrisCohen, "The Transformation of Retained Austenite into High-Speed Steel at Sub-Atmospheric Temperatures." *Am. Soc. Metals*, **30**, 1942, pp. 569–591.

7 Paul Gordon, Morris Cohen and Robert S. Rose, "Effect of Quenching-Bath Temperature on the Tempering of High Speed Steel." *Am. Soc. Metals*, **33**, 1944, pp. 411–454.

8 From "Internal changes during the Heat-Treatment of High-Speed Steel," a talk presented at the regular monthly meeting, Pittsburgh Chapter, American Society for Metals, April 13, 1944, by Dr. Morris Cohen, Associate Professor of Metallurgy, Massachusetts Institute of Technology.

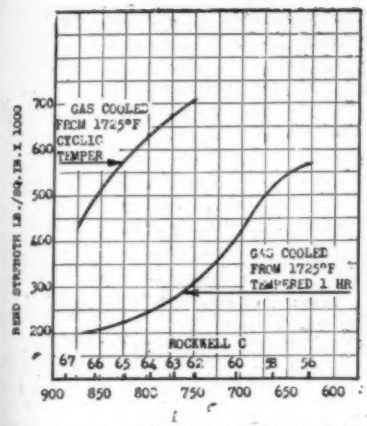

BEND STRENGTH LB./SQ.IN. X 1000
GAS COOLED FROM 1725°F CYCLIC TEMPER
GAS COOLED FROM 1725°F TEMPERED 1 HR
ROCKWELL C
67 66 65 64 63 62 60 58 56
900 850 800 750 700 650 600

Fig. 2.—Effect of cyclic treatment on the bend strength of a 1% C, 5% Cr, 1% Mo, air-hardening steel.

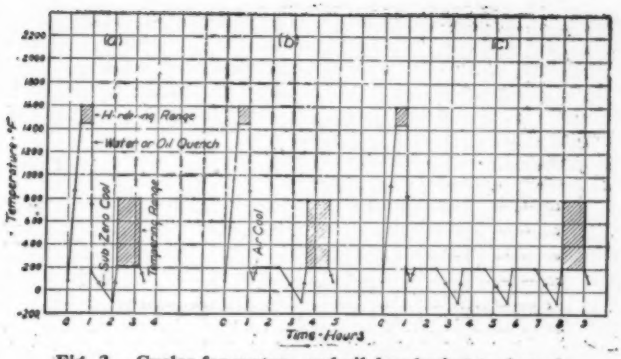


Fig. 3.—Cycles for water- and oil-hardening tool steels, alloy carburising steels, SAE 52100.

The curves indicate actual steel temperature. While the time relationships are not intended to be exact (except where specifically stated), it is significant to note that it is not deemed necessary to hold the steel at the sub-zero temperature for any appreciable length of time. It is important, however, that the steel reach the temperature given.

Treatments for the highly alloyed die steels, as shown in Fig. 4, are very similar except that two and sometimes more immersions in the sub-zero cooling medium are necessary to obtain optimum properties since the austenite is considerably more sluggish (that is, resistant to transformation). Somewhat inferior properties result from cycle (*b*) as against cycle (*a*) due to "ageing" (subsequently explained in the discussion on high-speed steel). Cycle (*b*) does, however, offer greater freedom from the cracking hazard.

Since steels that have been sub-zero treated have considerably greater strength at a given hardness they may be used at higher hardness than with ordinary heat-treating practice. By the same token, if breakage in service had been a serious problem previously, tempering to the same hardness as used with conventional treatment will produce much greater toughness.

Fig. 5 illustrates several cycles for high-speed steel. The regular salt bath technique may also be employed, the only difference being the air cool from the customary quench into a salt bath held at a temperature of approximately 1,100° F. High-speed steel, however, because of some anomalous behaviours, requires additional explanation. Cycles (*a*) and (*b*) are of equal effectiveness and would seem most likely to produce the best results in performance of all the heat-treatments given. It should be pointed out, though, that this is not definitely established. Berlien[9] and DePoy[10] have obtained opposing results on independently conducted service tests. Cohen[8] reported, however, that beneficial results have been obtained by sub-zero treating finished tools, which seems to indicate an "X" effect or factor that has, as yet, not been explained. It will be noted that even when the cooling is more or less continuous from the quench to the sub-zero temperature, double tempering is recommended. Cohen[6, 8] has shown this to be because the first cool still leaves approximately 9% of the austenite untransformed and no amount of time or a lower temperature will appreciably alter this condition. According to Cohen and Koh[11], it is, therefore, necessary to "condition" the remaining austenite by the first temper, so that it will transform on cooling to room temperature. Of course, it is desirable to stress-relieve this last formed martensite for best properites, hence the second temper.

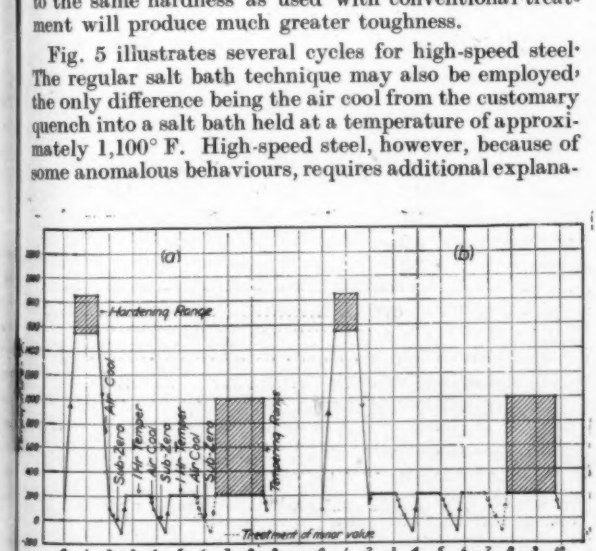


Fig. 4.—Cycles for Cr-Mo, Mn-Cr-Mo, and high-carbon, high-chromium air hardening tool steels.

It is appreciated that many tools, particularly large ones of complicated section and/or containing sharp corners or edges, would be prone to cracking if given either treatment (*a*) or (*b*). Hence the treatments shown by cycles (*c*) and (*d*) are offered. These may not produce properties equal to cycles (*a*) or (*b*), as pointed out above, but the improvement over conventional practice is considerable and they do provide a means of treating shapes that would be certain to distort or crack if sub-zero cooled directly.

In carrying out any of the treatments illustrated, the steel should not be held at or near room temperature for any appreciable length of time before sub-zero cooling, since the austenite becomes stabilised through an "ageing" phenomenon, and thereby becomes increasingly difficult to decompose. Gordon and Cohen[6] have shown that holding for as short a time as one hour has a detrimental effect and ten hours reduces the efficiency of the sub-zero treatment 50%. Furthermore, arresting the quench above approximately 225° F. is not recommended since a majority of the austenite would then not be transformed until the steel is cooled from

9 G. B. Berlien, "Sub-zero Hardening Cycles." *Steel*, Jan. 10, 1944, pp. 86–90.

10 Stewart M. DePoy, "Sub-zero Treatment of High-Speed Steels." *Iron Age*, April 13, 1944, pp. 52–55.

11 Morris Cohen and P. H. Koh, "The Tempering of High-Speed Steel." *Am. Soc. Metals*, 27, 1939, pp. 1015–1051.

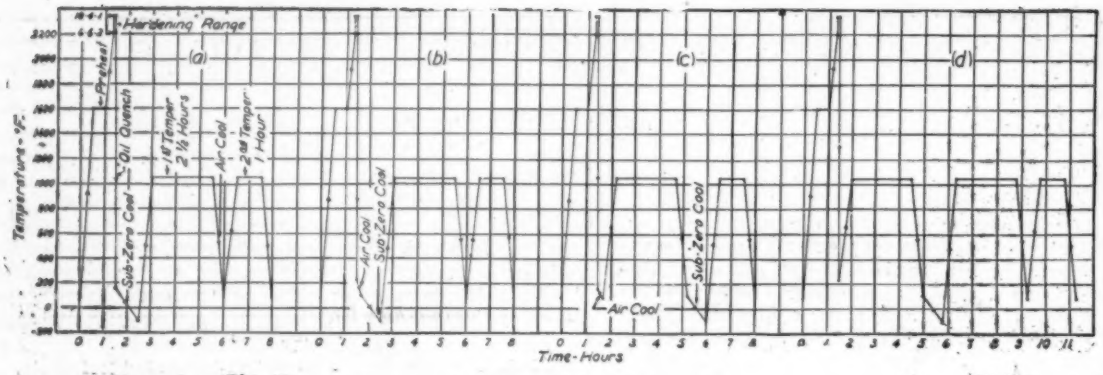


Fig. 5.—Cycles for high-speed steels.

the tempering temperature with an even greater hasard of cracking. Specific tempering times are given for high-speed steel because they are of considerable importance. According to Cohen[8] the first temper, if less than 2½ hours at 1,050° F., will not permit sufficient precipitation of carbides at the tempering temperature to allow for complete transformation of the retained austenite on cooling, while more than three hours causes some loss in both room temperature and hot hardness, strength, and toughness.

In closing, it is felt desirable to add some further precautions that have been dictated by actual experience. Since the distortion and cracking hasard is ever present when transforming austenite to martensite at such low temperatures, it is desirable that the temperature of the part be as uniform as possible to prevent additional thermal stresses. Many users of the process have, consequently, employed the practice of surrounding the part with one or more layers of heavy wrapping or asbestos paper before insertion in the cooling medium to slow up the cooling somewhat. Users are also cautioned to avoid making hardness tests, particularly with heavy indenters, until the part has been tempered.

The Non-Ferrous Industry in Canada: Increased Activity, Reduced Value of Processing

ONE of the most important features in the United Nations' position with regard to supplies of the non-ferrous metals is that Canada, although long a substantial supplier of the raw materials from which they are produced, had practically no refinery capacity in 1914, whereas during the present war the Dominion has been able to furnish the Allies with large quantities of copper, nickel and zinc, and other metals in a refined state.

The extent, nature and changes in the non-ferrous industry in Canada during last year are well brought out in the statistical analysis of this industry, just released by the Dominion Statistician.

PRINCIPAL STATISTICS OF THE NON-FERROUS METALLURGICAL INDUSTRY IN CANADA, 1941-1943.

	1941.	1942.	1943.
Number of companies	9	10	9
Number of plants	13	15	16
Capital employed ..... $	309,963,342	356,052,965	392,217,156
Number of salaried employees	1,750	2,625	3,375
Salaries ..... $	4,117,398	5,286,755	7,160,290
Number of wage-earners	14,264	18,537	23,374
Wages ..... $	23,365,291	32,053,801	41,331,442
Value of Ipant products (gross) ..... $	*379,322,270	447,617,199	511,213,376
Estimated cost of ores, concentrates, etc., treated (*a*) ..... $	213,542,005	258,903,818	317,917,186
Cost of fuel and purchased electricity (*b*) ..... $	26,771,809	35,748,639	43,165,110
Process supplies, other than items (*a*) and (*b*) ..... $	19,272,162	27,083,695	38,334,0
Value added by smelting (net) ..... $	119,736,294	125,881,047	111,857,06

—2

* The gross value of production should not be interpreted as the ultimate sale value of finished metal only, as it represents the combined values of all industry (smelting, refining, etc.) end products (blister, copper matte, etc.), and in this sense represents a duplication in values.

According to this survey, the industry comprises those firms previously engaged in the smelting of non-ferrous ores or concentrates and the refining of the metals recovered from them, and the magnitude of this industry in Canada may be gauged from the fact that the net value added by such processing in 1943 was $111,857,000, compared with the record of $125,881,047 in the previous year. This 12·3% decrease does not altogether reflect a general decrease in metal output, but rather the gradual increase in mining, smelting and transportation costs resulting from war-time conditions.

The salient features of the non-ferrous industry in Canada are summarised in the accompanying table.

The Annealing of Copper Wire

THE use of the "top-hat" type of furnace for the annealing of copper wire is well known. Recently a small experimental unit was used by the London Electric Wire Co. and Smith's Ltd., at their works, under the supervision of their technical staff for determining approximate working consumptions and efficiencies for this process. The results are of considerable interest, and even better efficiencies can be obtained with larger units.

Number of reels per batch	2
Weight of copper per batch	60 lb.
Heating time	15 min.
Maximum temperature recorded	550° F.
Gas rate per hour	88 cub. ft.
Total gas consumption per batch	22 "
Gas consumption per lb. of wire handled	0·367 "
Gas consumption per ton of wire handled—	
(*a*) 821 cub. ft. (480 B.Th.U. per cub. ft.)	
(*b*)	3·94 therms
Cost of fuel per ton at 6·25d. per therm	24·6d.
*Estimated heating efficiency	28·7%

* Based upon theoretical heat input required to raise the copper only in each case to the required temperature, using formula—

$$\frac{WST}{GW}$$

where W = weight of copper handled; S = specific heat of copper; T = temperature rise in ° F.; G = gas consumed in cub. ft.; C = calorific value (B.Th.U. per cub. ft.).

The Future of the British Steel Industry

By Sir Alexander Dunbar

(*Chairman, English Steel Corporation, Ltd.*)

The iron and steel industry is a basic industry upon which practically every other industry depends and it is one of the industries which will be expected to make the transition from war to peace conditions in the least possible time. Thus, reorganisation and reconstruction plans must be given effect while endeavouring to maintain a high level of production. The future of such a vital industry is obviously directly concerned with the economic future of Britain and all views which contribute to speeding the transition period are of great value. The subject was freely discussed in our July, 1944, issue, but, in a recent lecture to the Sheffield Metallurgical Association, Sir Alexander Dunbar shed more light on the problem and gave his views in a brief survey of the steel industry, the main features of which are given in this article.

IN any consideration of the future of the British steel industry the first question that inevitably arises is that of nationalisation or private enterprise. May I say at the outset, quite emphatically, that I support private enterprise and ownership. Whatever may be said in theory—and there are quite a lot of sound theoretical arguments in favour of state ownership—I am convinced that nationalisation of the steel industry, at this stage of our national development, would be nothing short of disastrous. But, if the steel industry is to do its duty to the community and to play its part in the national policy of full employment, it must recognise its obligations as a basic supplying industry and it must be prepared to place national efficiency before individual gain.

Interdependence of All Sections of Industry

One lesson this war has driven home is the interdependence of all sections of industry and all classes of the community. The nation cannot afford to run its affairs in a series of watertight compartments and industry is the affair of the nation. It is futile to consider the future of the steel industry as a separate entity ; it must take its place in an ordered scheme of national industrial organisation. It is even more futile to attempt to consider the future of any branch of the steel industry —such as the Sheffield trades for instance—without relating it to the steel industry as a whole.

For some years to come, while the individualistic requirements of British engineering continue, there will be a useful niche to be filled by the small man in the steel industry, such as, for instance, the independent re-roller with a specialised trade ; but, in productive industry, large scale planning must be on the basis of national efficiency and in the steel industry this can best be obtained by a larger number of large scale integrated plants.

National efficiency entails, among other things, co-ordination on the broadest possible basis, i.e., on a national basis, unfortunately, however, the existing organisation of Government does not readily lend itself to this course. For this reason it was necessary to form a Ministry of Production to co-ordinate the requirements of the three Supply Ministries. For the same reason, even during hostilities and however great the urgency, a new factory could not be started without the approval of far too many different authorities, some national and some local.

National Efficiency

The lesson we must learn is that the problems of rehabilitation after the war will demand national efficiency just as much as the exigencies of war itself. Nothing less than national efficiency will see us through, and to obtain this we must continue to have some form of central direction. Whatever the political shade of the Government, its duty will compel it to intervene in the affairs of industry to a much greater extent than ever before. That I regard as inevitable and none should resent it. It is a perfectly proper thing to do and those who shout about letting industry run its own affairs, without any form of Government supervision, are thinking only of their own pockets and not of the country as a whole.

These views may give the impression that I am veering towards nationalisation. The machinery of Government may require overhauling—I think it does—but essentially it is perfectly competent for the direction and co-ordination of industry. It may have to be augmented here and there by the appointment of specialist bodies, which is quite normal procedure, but it most definitely is *not* competent to run industry or any branch of industry in a competitive market. Most of us are in business primarily for the money we get out of it and if the the profit motive is removed, as under State ownership, the most powerful incentive to technical progress and efficiency is taken away.

But if we are to be allowed, within the limits of national policy, to run our own affairs, we must have a structure which will satisfy the Government and the public that we are competent to do so with due regard to our obligations as a basic supplying industry, *and* to our employees, *and* to the people who invest their money in the industry. I believe that in the reconstituted Iron and Steel Federation we have such a structure.

One of our national obligations is to assist, in every possible way, the Government policy of full employment ; this can be divided into two parts. First, the steel industry itself should provide maximum employment, and secondly—and much more important—it must help the great consuming industries on which the country is so much more dependent for employment and export trade.

Maximum employment within the industry can obviously only be attained if we lay down capacity to

produce the whole of the steel required by the country for both home and export trade. But the provision of steel making facilities is a very expensive business, and steel furnaces, once started, have got to be kept in production. The industry cannot be expected to produce the maximum requirements of the country unless there is some reasonable guarantee that the Government will take steps to overcome the variations in the trade cycle. This cannot be tackled by the industry; it is so intimately linked up with international arrangements and particularly with the monetary policy of the country, that it can only properly be tackled by the Government.

One of the most encouraging things for the future well-being of this country, is the Government White Paper on full employment, which was published some months back. It shows such a welcome change of heart on financial policy and such a breadth of vision, that it augurs well for industrial prosperity in the future on a more stable basis than we have ever before experienced.

In the pre-war years, it was the policy of the steel industry to rely to a considerable extent on the import of semis and this has been a kind of safety valve which we so organised as to take up the slack of trade cycles. When trade was good, we imported a lot of steel; when trade was bad, we reduced our imports by means of tariff protection and still managed to keep our own plants operating at a reasonable level of capacity. I believe that in the future we will make *all* the steel the country requires, and by means of the more enlightened Government policy I have mentioned, we will be able to keep our plants reasonably occupied and so provide increased and *steady* employment within the steel industry.

More important than increased employment in our own industry, is the help we can give to the great consuming industries such as general engineering, shipbuilding, chemical engineering, electrical engineering, the motor trade, etc. The consumers of steal, in the aggregate, employ and can employ far more people than we can and they can extend their export trade more readily and to a greater extent, and the export of finished products is much more beneficial to the country than the export of steel which, to many people, is merely a raw material.

To give these great industries the assistance they are entitled to expect means that we must give them steel of the best possible quality, and we should give it to them at a price which is comparable with the price paid by other competing countries. But before I talk about price, I would like to say that one way in which we can assist the consuming industries—and this applies garticularly to the Sheffield heavy trades—is to give them the steel they want in the cheapest and most economical form. To enable us to do this, the consumers must consult with the steel industry at the earliest possible stage, and the earliest possible stage is when their projects are in the design stage. There has been too little of this in the past. It is now one of the objects of the steel industry to arrange the earliest and most detailed friendly collaboration with the consuming trades. Whether we are thinking of large vessels for the chemical engineers, rotor shafts for the electrical industry, castings for the plant makers, or drop forgings for the motor industry, we know that we can help them if they put their problems in front of us at the earliest possible stage, and I am equally sure that close collaboration with these manufacturing industries will give us many useful hints which will enable us to improve our own organisational technique.

The Question of Price

When we talk about price, it must be remembered that our costs are, to a considerable extent, dependent on the price we have to pay for our raw materials and for transport and other matters which are quite outside our own control. The most important factor of all is the price of coal; the foundation of industrial prosperity is not cheap steel, but cheap coal. Whereas steel prices have increased by about 50% since the beginning of the war, coal has gone up a 100% and coke has increased by about 130% It is unfair to press us to sell our steel at the same price as other countries if we start off with such a handicap. I can illustrate quite simply by pointing out that in America, a ton of finished steel costs £2 for coal, while in this country it costs us £4. What we *can* do and what we *must* do, is to continue our research into fuel economy, and in this respect I think there are probably much greater opportunities for reducing coal consumption in the production of pig iron, than in steel melting and treatment.

Another important factor is iron ore. Much as I like the policy of using our own materials, I am convinced that, after the war, we must revert very largely to the use of imported ores of high iron content. In this conconnection ocean freight rates will be very much higher than prior to the war.

Even before the war, and again recently, the steel industry has been criticised on this matter of price, though much of the criticism has been singularly ill informed. Until quite recently a large proportion of the general public were under the impression that we were inefficient and that by our system of price control we made an unjustified profit at the expense of the consumer. Thanks to the vigorous steps taken by the Federation, that erroneous impression has been largely removed and there is now a greater understanding of our position. Although our record is a creditable one we cannot afford to sit down in complacency. There is still a tremendous amount to be done in continuation of the policy of modernisation which was started ten years ago.

The steel industry is fully alive to what is needed and not only have plans been formulated but these plans have been studied from the point of view of fitting into a broad national picture; duplication or possible duplications have been and are being weeded out; the inevitable conflict of interests between different firms in the same section of the industry are being smoothed out; and the extent to which we shall draw on the resources of the building trade, electrical industry, etc., has been worked out. The steel works plant industry has been kept fully in touch with what it will be required to provide, and the Government has beem fully informed. These plans involve the expenditure of well over a hundred million pounds, it will give you some idea of the enormity of the problem.

There is one other national obligation that I have not yet mentioned, though it is one of the most important. It is our duty to assist British engineers to maintain their technical supremacy in the competitive markets of the world. British engineering products are renowned the world over for their excellence in design and quality—a most important factor in obtaining orders for export trade. This is a question which is of particular importance in the world of alloy steels, and

for the assistance that has been given in the past to British engineering, Sheffield and Sheffield metallurgists have a reputation of which they may be justly proud.

Research and Cartel Questions

There are two other matters of such vital importance in any consideration of the future that must be mentioned. The first is the question of research, and on that point it is noteworthy that a new and strengthened Research Association has been formed by the Iron and Steel Federation and the Iron and Steel Institute. Research in the steel industry is carried on to such an extent within the varied works that it is difficult to say just how much is spent each year on this vital matter, but, whatever it amounts to, it is certain that the expenditure in post-war years will be considerably increased and technically I am confident that we will remain in the forefront of world progress.

The other matter is the vexed question of cartels. One of the principal troubles about international cartels is that the people who speak and write about them are lamentably ignorant of their subject, and the people who know from practical experience all about cartels are silent. The word "cartel" has had so much mud slung at it that it must be replaced, but whether we call it international planning or anything else, and whether arrangements are made by Governments, by industry, or by a combination of both, there is not the slightest doubt that international arrangements of some kind are absolutely essential to the future of world trade. The trade agreements arranged between Governments in pre-war days were not nearly so beneficial to this country as the international cartels, such as the steel cartel, which was arranged between industrialists. It is true that in some cases, the arrangements had, or might have had undesirable restrictive consequences and I agree that future arrangements must be free of this possibility. But international planning arrangements are essential and I hope that no Government will attempt to make such arrangements without full co-operation with the industry concerned.

In this brief survey it has only been possible to touch a few of the more vital questions. No effort has been made to direct attention to the problems of Sheffield, because they must be tackled on a broad national basis. In particular, nothing has been said about the development of stainless steel, although this section of steel-making, born, cradled and nurtured in Sheffield, is going to expand to an extent that few people outside of Sheffield realise. No reference has been made to provision of educational facilities, but this is certainly a subject on which industry—not least the steel industry—must give attention in the post-war world. My main desire has been to emphasise the fact that the future of the steel industry is not an isolated problem and that it must take its place within the framework of a comprehensive scheme of national policy. It is to the basic fundamental principles involved that I have endeavoured to direct the thoughts of interested readers.

Reviews of Current Literature

Steel Plant Refractories

In our September issue, last year, attention was directed to a book on the above subject about to be published by the United Steel Companies Ltd. It has now been published and to those interested in this aspect of steel works operations we have no hesitation in saying that his book exceeds our expectations. It is particularly opportune that it should be published at this time to show the efforts being made to reduce cost in steel works where savings can be effected within the industry. In view of the criticisms levelled at the British iron and steel industry, by people who have little or no knowledge of it, there is a feeling of gratification that the industry is not adopting the obsolescent methods that some would have us believe.

Several books have been published which deal with refractories, but we believe this to be the first on steel plant refractories. The author was the first student in this country to receive the degree of Doctor of Philosophy for a thesis on refractory materials. He continued his research in Germany and the United States and in 1934 he joined the staff of the United Steel Companies Ltd., and took charge of the refractories section of the newly formed Central Research Department.

As mentioned in a Foreword by the late Dr. T. Swinden, the book admirably blends fundamental research with practical experience. The author describes the methods found useful in testing refractories, the properties of the principal materials used and the conditions existing in steel works furnaces. Much of the information has been published, but it is so widely scattered through the literature of the steel and refractories industries, that a great service has been performed in bringing it within one cover. This information is supplemented by a section on the statistical treatment of test data and by twenty-one appendices giving the information needed by the refractories technologist in his day to day work.

Refractories are undoubtedly a major item in steel plant costs, in addition, however, they are an important factor limiting the development of faster and more durable furnaces. By means of detailed information given in this book, the author suggests the best refractories to use in the numerous positions on the whole range of steel plant furnaces, the life that can be expected, the usual causes of failure and possible line of improvement. The three main sections of the book are concerned with testing refractories, furnaces, and casting-pits, respectively. Methods used in testing refractories in Great Britain and America are discussed in chapter I, which also gives a simplified description of the application of statistical methods—e.g., quality control charts, correlation co-efficients, etc., to test data. Chapters II to VII are concerned with particular materials, such as silica, magnesite, dolomite, chrome, and chrome-magnesite, and alumino-silicates, and with insulation. Fundamental data on pure oxides and oxide systems are included, and for commercial raw materials, methods of brick and clinker manufacture, brick properties and applications.

The remainder of the chapters from VIII to XIV are concerned with basic and acid open-hearth furnaces, with acid and basic Bessemer, electric steel plant soaking pits and repeating furnaces, and with the casting-pit. Each type of furnace is considered from the

standpoint of construction, choice of refractories, life and causes of failure and future lines of development. A comprehensive bibliography is appended to each chapter.

The book, which contains about 500 pages of text and illustrations, is admirably produced and, while it will be appreciated that great progress has been made in refractories in the last twenty years, it is felt that this book greatly adds to the vast possibilities of the future. That it will be regarded as a standard work on the subject for many years to come has been mentioned to the reviewer on several occasions and there is no hesitation in endorsing this view.

By J. H. Chesters, with a Foreword by the late Dr. T. Swinden. Published by the United Steel Companies Ltd., 17, Westbourne Road, Sheffield, 10. Price, 36s. net.

The Efficient Use of Fuel

The drive for fuel economy is of major importance to the war effort, and will be of equal importance for the reduction of costs of production after the war. The progress which the fuel efficiency campaign has made has aroused in the minds of those engaged in industry a desire to know more of the subject. Lectures, works visits and brains trust meetings which have been held in all parts of the country under the auspices of the Ministry of Fuel and Power have been attended by some 20,000 engineers, works managers, boiler and furnace operatives and others. The desire has been repeatedly expressed at these meetings that an authoritative textbook should be made available, containing a permanent record of the subject matter of these discussions and lectures. This book has been issued as a comprehensive work to meet this need and has been designed to give the whole story of the practice and principles of fuel utilisation. In preparing it the Fuel Efficiency Committee of the Ministry of Fuel and Power has had the co-operation of over 200 experts comprising most of the leading authorities on fuel utilisation in the country.

In undertaking this task the committee realized that no single existing textbook covers both the fundamental principles and the essential operating features necessary to obtain satisfactory results. The result is unique in that for the first time there has been gathered into one volume material for which previously it would have been necessary to consult perhaps 20 or more standard books. It is written in a form easily understandable and is equally suitable for students of all ages and for the busy man in the works.

Every works engineer, every member of the technical and administrative staff of works, which use fuel for any purpose, every fuel watcher, should have access to this important volume. It should find a place on the bookshelf of everyone who has anything to do with fuel and in the library of every works in the country.

Published by H.M. Stationery Office, 34 chapters, vii + 807 pp., 303 illustrations, price 12s. 6d. net; 13s., post free.

David Brown & Sons (Huddersfield) Limited have notified us that they have opened an area office at 70, Queen Square, Bristol, 1. The telephone number is "Bristol 21830," and the telegraphic address :" Gearing, Bristol."

Personal

Mr. James G. Arnott, for the past 10½ years Foundry Manager of the Clyde Alloy Steel Co. Ltd., and well known in Marine Engineering circles, has joined G. and J. Weir, Ltd., as general manager of the Holm Foundry, Cathcart, and Argus Foundry, Thornliebank, in succession to the late Mr. Norman McManus.

Mr. J. Blakiston, A.M.I.Mech.E., of Modern Foundries Ltd., subsidiary company of William Asquith Ltd., Halifax, has been granted leave of absence to visit important Indian foundries on special duty. Mr. Blakiston is president of the West Riding Branch of the Institute of British Foundrymen.

Mr. Frank H. Saniter, B.Sc., has been appointed Director of Research to the United Steel Companies Ltd. In making this announcement the Company advise us that their research activities, including those relating to metallurgy, applied mechanics, and manufacturing processes, are now to be unified and co-ordinated under a single control. Thus, the position rendered vacant by the death of Dr. Swinden becomes one requiring experience of a general character rather than of an essentially scientific nature.

Mr. H. H. Shepherd, F.R.S.A., chief metallurgist and foundry consultant to Crane Ltd., Ipswich, with whom he has been associated rather more than eighteen years, has resigned from the company's service in order to take over the appointment, on March 1st, of chief metallurgist and technical assistant to the iron foundry departments of Messrs Sterling Metals Ltd., Coventry.

Mr. F. Pickworth, F.C.I.S., has been appointed managing director of the English Steel Corporation Ltd. and its subsidiaries, The Darlington Forge Ltd., and Industrial Steels Ltd. On the formation of English Steel Corporation Ltd., in 1929, Mr. Pickworth, chief accountant of Cammell Laird & Co. Ltd., became assistant secretary, being appointed secretary the following year and subsequently a special director. Since his appointment as a director in 1936, he has been in control of finance and administration and of the planning, construction, and modernisation of works and plant, including large extensions on behalf of the Government ; in addition, he has had charge of the sales organisation since the beginning of the war.

Mr. D. A. Oliver, M.Sc., F.Inst.P., research director of William Jessop & Sons Ltd. and J. J. Saville & Co. Ltd., Sheffield, is also director of research to the Birmingham Small Arms Group, of which Jessop's and Saville's form part. The B.S.A. Group research activities, in addition to being carried on in the laboratories situated at the different works of the Group, notably The Daimler Co. Ltd., Coventry, The B.S.A. Co. Ltd., Birmingham and B.S.A. Tools, Ltd., Birmingham, are being expanded.

Recent additions to the research staff of the B.S.A. Group Research Centre include Dr. A. J. Bradley, M.A., F.R.S., and Mr. P. H. Lawrence, B.Sc. Mr. H. W. Pinder, Assoc.Met., F.R.I.C., for several years responsible for metallurgical research under Mr. Oliver, is now in charge of technical sales in the Jessop-Saville organisation.

Platinum and its Production

By A Special Correspondent

The importance of platinum to industry is rarely appreciated. It is true that world production is very small compared to the base metals, but its value in industry and research and its apparently limited quantity places it in the class of important industrial metals. This brief review, dealing with some historical aspects, production of the metal, and some of its properties and uses, will be of interest.

PLATINUM gets its name from the tiny, silver-like particles discovered ever and again in gold-bearing places of the River Pinto in Colombia, which were termed Platina del Pinto, hence eventually platinum. These tiny particles were in actuality crude platinum, which metal was first discovered in Colombia, where it was employed decoratively in the form of spangles, beads, and the like. It was some considerable time, however, before the potential value of the metal was realised, because it could not readily be melted or worked owing to its high melting point. It was generally discarded when found in course of mining for gold, and virtually the only commercial use to which it was put was for making false money. The doubloons of which we used to read in our childhood as being found in treasure hoards or in sea-captains' chests may have been spurious! The counterfeiters, as a fact, were Spanish adventurers. The coins were plated with gold to make them look real, and the period during which these spurious coins were in circulation was between 1730 and 1772.

Platina del Pinto did not arrive in the mother country until 1741, but it was immediately seen to have extraordinary qualities, and experiments were carried out on it with fascinating results. The upshot was commercial exploitation of the Colombian deposits in 1778. Forty-five years were to elapse before, in 1823, new deposits of economic value were discovered in the Urals, which led to the industrial working of these deposits twelve months later. From that date onwards, Russia became what she still is, the greatest producer of alluvial platinum.

Platinum is widely distributed, though not all the localities in which it is found can claim to have large deposits. On the other hand, the minerals from which it is obtained are not numerous. The principal is native platinum and its alloys, and sperrylite, the arsenide. Less important are cooperite and braggite, both sulphides.

Native platinum is usually found alloyed with other platinum metals such as palladium, iridium, rhodium, etc., and with iron. Other metallic elements may also be present. This native platinum has a specific gravity of 14–19, as against the specific gravity of the pure metal, which is approximately 21·5. The colour is a steel grey verging towards white. The composition of the native platinum depends, of course, on its origin, but is pretty much as follows:—platinum 60–90%, osmiridium up to 27%, iridum up to 7%, rhodium up to 2%, palladium up to 3%, gold up to 2%, copper up to 4%, iron 2 to 16 %. In addition the iron, if of a nickel-bearing type, may contain small percentages of nickel and cobalt.

Sperrylite ($PtAs_2$) is a crystalline mineral, of silvery-white hue, having a brilliant metallic sheen and a black streak. Its specific gravity is 10·6. It was originally discovered in 1889 in copper nickel ore at the Vermilion Mine near Sudbury, Ontario, Canada. Native platinum is found in Russia, Colombia, Sierra Leone, Abyssinia, the Yukon, New South Wales. Sperrylite is found not only in Canada, but also in South Africa.

Cooperite (PtS) is also found in South Africa, and is a steel grey tetragonal sulphide; South Africa also produces braggite (PtPdNi) S, laurite (RuS_2), and similar minerals.

Platinum metal is usually found in olivine-rich rocks (dunite, etc.) and similar ultrabasic igneous rocks. It is found in sulphides of nickel, copper, and iron, associated with gabbro and kindred basic igneous rocks. Finally, it is found in placers, including both alluvial and eluvial deposits.

Platinum is mined or largely the same lines as gold. The prospective source is first drilled or pitted or even both. Open workings have the overburden stripped off, the pay dirt washed, and the tailings removed. Where the working is below ground, as in the U.S.S.R. and Alaska, shafts and drives may enable the operator to dispense with stripping.

Modern practice in both Russia and Colombia is to use electrically operated bucket dredges. In Tasmania and on numerous other alluvial properties, hydraulic plant is employed for stripping, or even hand labour, together with sluice boxes for washing. As, however, to separate platinum from black sand is always difficult, practice has to be modified in accordance with individual circumstances.

There are various methods for concentration, of sulphide ores according to the type of ore concerned. Space does not allow of our detailing them all, and we will content ourselves with indicating that the most usual appears to be gravity concentration succeeded by flotation. The gravity process produces a clean platinum sulphide concentrate which is immediately refined. Flotation produces a concentrate comprising a platiniferous mixture of copper, nickel and iron sulphides, with some gangue.

The refining process comprises dissolving the crude platinum in aqua regia, precipitating platinum with ammonium chloride as ammonium platinichloride, and calcining the precipitate, which decomposes at a low temperature leaving a spongy residue (spongy platinum). Lastly, the latter is compacted by pressure followed by forging at a high temperature.

Platinum is melted to-day by means of the high frequency electric induction furnace, in which heat is induced in the metal by a current of high frequency electricity, which sets up eddy currents in the metal. This furnace allows of high temperatures, quickly obtained, together with excellent control of furnace atmosphere, or even melting *in vacuo*. The absence of

fuel prevents contamination of the metal, and the violent electrical stirring of the metal makes for efficient mixing and alloying.

Where the high-frequency furnace is not employed the metal is usually melted in an oxy-hydrogen or oxy-coal gas flame in a lime furnace. This comprises two blocks of lime of concave form, like saucers, fastened together in a casing of strong sheet iron. A blowpipe is inserted through a hole in the top block. The bottom block is grooved on one side of its upper edge to make pouring easier. The entire fixture can be tilted for pouring into a pre-heated mould of graphite.

The metallic platinum ingots thus produced can be forged, cold rolled, cold swaged, drawn and spun. Seamless tubes can be made from it. Punching and machining both present difficulties owing to the softness of the metal. It can also be hammer welded.

A point worthy of note is that there is a considerable secondary production of platinum, quantities of the metal being recovered from scrap, skimmings, dross, sweepings, residues, and used metal of numerous types. It has been estimated that 25% of the material required by platinum importing countries is recovered in this way.

Platinum has considerable economic importance, in addition to its use for ornament. It has a high melting point, considerable heat-resistance, corrosion resistance is high, and resistance to oxidation at normal temperatures is also high. The metal is known in three forms, black platinum, spongy platinum, and compact platinum. Of these, the last is the most effectively resistant, and the black metal the least.

The melting point of the metal is 1773° C. Its specific heat is 0·0324 at 20° C. Its coefficient of linear expansion at 40° C. is $8{\cdot}99 \times 10^{-6}$, and at 1000° C., $11{\cdot}30 \times 10^{-6}$.

Thermal conductivity (gm. calories) at 18° C. is 0·1664, and at 100° C., 0·1733. Electrical resistance in ohms per mil. ft.-at 0° C. annealed is 60·0. Temperature coefficient of resistance per ° C. is in the hard state, 0·003917 at 0–100° C. ; in the annealed state, 0·003923 at 0·100° C., and 0·00318 at 0–1200° C. Ultimate strength for hard wire of 0·02 in. diameter is 21·6 tons per sq. in., and for annealed wire of the same diameter, 9·5 tons per sq. in. Elongation on 2 in. for equivalent wire is 0·8% for hard and 32·0 % for annealed. Brinell hardness is 50 for cast metal, 97 for hard metal, and 47 for annealed metal.

There are numerous important alloys of platinum, among which may be mentioned platinum-iridium, platinum-palladium, platinum-rhodium, platinum-gold, platinum-silver, platinum-copper, platinum-nickel. The economic uses of these are as follows :—Platinum-iridium —jewellery, etc. Platinum-palladium, for uses where a softer platinum alloy is required ; platinum-rhodium, for high-temperature furnace windings and for laboratory crucibles ; platinum-gold, for solders, spinnerets, and other parts where ductility is required. Platinum-silver, for swaged dentures and other dental materials. Platinum-nickel, for heating filaments of radio valves.

The principal outlet for platinum and its alloys lies in the following industries :—jewellery, chemical, electro-chemical, electrical, dental. Of these 54% was absorbed by jewellery in 1933, and 18% by the chemical industry.

In the chemical industry, platinum is used for crucibles, dishes, foil, wire, tweezers, tips for crucible tongs, and in numerous scientific instruments. Many platinum metals are employed in the chemical industry for catalysis. Platinum is also employed as electrodes in various processes of an electro-chemical character, e.g. in making persulphates.

Another important use is for resistance thermometers, and for the thermocouples of temperature measuring instruments.

In the electrical industry, platinum alloy points are employed for electrical contacts where absolute trustworthiness is required, and platinum by itself when the mechanical load is not severe. Platinum-iridium alloys are used for magneto contacts. Platinum is also used with other metals for purposes already detailed.

Considerable progress has been made of recent years in the electro-plating of platinum on watch cases, toilet sets, coffee services, trophies, and medals. The coating is attractive, even, and does not tarnish. Other applications of platinum alloys include hypodermic and cautery points in surgical work, X-ray valves, fuse-wires for explosives, non-magnetic parts of high quality watches and chronometers. Platinum black is employed in automatic gas lighters and self-lighting lamps. Platinum salts are not now much employed in photography owing to their comparatively high cost. Platinum in solution with intricate organic compounds in essential oils and known as liquid bright platinum has been and still is employed in ornamenting pottery.

The production of platinum, taking the latest figures of the Imperial Institute (1938) show that Canada is first in the field with 161,319 troy ounces of platinum, recovered from Ontario nickel-copper matte, and from seven other sources. The U.S.S.R comes second with 120,000 estimated troy ounces production of crude platinum. Next comes the U.S.A. with 42,043 oz.; Colombia with 29,460 troy oz. ; the Union of South Africa produced 18,256 ; Abyssinia 8,038 (in 1936); Sierra Leone, 180 ; New South Wales, 46 (in 1937); Japan, 34 (in 1938) ; Papua, 20 (in 1937). The world consumption of platinum in 1934 is estimated by the Imperial Institute to have been approximately 200,000 oz.

In the British Empire, platinum has been found in the United Kingdom, but the deposits are of no economic importance ; in Kenya and Nyasaland, where further investigation may prove the deposits to have value ; in Sierra Leone, as already mentioned ; in Somaliland, where results seemed at first to show promise, but afterwards proved disappointing ; in Southern Rhodesia, where production has been abandoned; in Canada, where apart from the enormous recovery industry, the metal is only found in small deposits of alluvial character in British Colombia ; in Newfoundland ; and in British Guiana, but not in quantities large enough to warrant economic exploitation.

India used to produce small quantities of platinum metals, but has been out of production for about 23 years. Australia and the Union of South Africa have already been dealt with. Papua may prove a possible future source of some importance. New Guinea has also unexplored possibilities. New Zealand has widespread platinum, but has not ranked and does not appear likely to rank as a producer of maximum importance.

Countries outside the British Empire in which occurrences of platinum are known include, in addition to those previously mentioned, France, Germany, Madagascar,

the Belgian Congo, Argentina, Brazil, Chile, the Netherlands East Indies, and the Philippine Islands. In Brazil, such production of platinum as has occurred has always been as a by-product of some other mining operation.

The marketing of platinum has produced some extremely good examples of competitive haggling and complete failure to produce an effective international agreement. The U.S.S.R. was for many years opposed to any effort to stabilise prices, but eventually in 1931 became associated in an international agreement, which, however, was not completely successful in its operations Some efforts have been made to adopt a hall mark for platinum on the lines of the hall mark for gold, but so far no specific agreement on this point has as yet been reached.

Obituary

Mr. PERCY PRITCHARD.

THE announcement of the death of Mr. Percy Pritchard, F.R.Ae.S., M.I.A.E., of Edstone Hall, Wootton Wawen, the deputy chairman and joint managing director of Birmid Industries Ltd., would come as a great shock, not only to his wife and family, but to his colleagues and the many in industry by whom he was held in high esteem. In the Midlands especially he will be a great loss.

Mr. PERCY PRITCHARD.

He was a man of great gifts and possessed of brilliant mental capacity and unbounded energy. In 1914, in conjunction with Mr. Arnold Pearce, he started a small iron foundry for the manufacture of motor cycle cylinders and from such humble beginnings built up the large group of metallurgical engineering companies which have achieved such signal success and which employ upwards of 10,000 people. He had a scientific and analytical mind, which cut to the root of any problem with exceptional rapidity and precision, and his grasp of finance was phenomenal in a man whose interest was applied science.

Mr. Pritchard was chairman of the Midland Regional committee of the Employers' Federation, President of the British Cast Iron Research Association, member of the British Non-Ferrous Metals Research Association, member of Council of the Wrought Light Alloys Development Association, member of the British Institute of Foundrymen, by which he was awarded the Fox Gold Medal in 1941, and a member of the Institute of Metals. He was also a Fellow of the Royal Aeronautical Society and a member of the Institution of Automobile Engineers, upon whose Council he had served. At the outbreak of war he became director of the Light Alloy Control (Castings).

He was a great believer in technical education and was convinced that the salvation of this country in the post-war years could be achieved only through the technical excellence of its products. He was an affectionate and kindly man and he will be greatly missed in many fields of industrial activity.

Mr. CECIL KINDER.

The death of Mr. Cecil Kinder, Director of Specialloid, in a recent railway accident at Kings Cross, creates a gap not easily filled. He was a delightful and charming personality and his death is not only a great loss to his colleagues, but also to all with whom he came into contact. He will be sorely missed.

Design and the Designer in the Light Metal Trades

In connection with the many plans prepared for the development of post-war industry considerable attention has been given to the question of design. Various committees have been set up, at the request of the Board of Trade, to encourage by all practical means the adoption of good design in British industry. Such a committee was set up to consider how to give practical effect in the Light Metal and Allied Trades to recommendations in design and the designer in industry ; a report of this committee is given in this 58-page book.

Divided into two main parts, embracing design in the factory, and design and training for design, the report provides much food for thought. The first part describes what constitutes the light metal trades and design in relation to their products is discussed under such headings as hearth furniture, hollow-ware, aluminium hollow-ware, miscellaneous hardware, enamelled signs, electric fittings, architectural metalwork, and fancy brass goods. The second part is concerned with the designer and his or her training in which are discussed the existing facilities for training and the committee's recommendations.

Published by H.M. Stationery Office, price 1s. net.

Errata

Page 117 : The footnote should be numbered 3, 4, 5, 6, instead of 4, 5, 6, 7, respectively. Also the end of the second line of footnotes should read, " See note 4," instead of " See note 5."

Page 118 : The footnote should be numbered 7, 8, 9, 10, 11, instead of 8, 9, 10, 11, 12, respectively.

100 Years of Aluminium

By Freeman Horn

(*The British Aluminium Co. Ltd.*)

While it is true to say that the real beginning of the aluminium industry resulted from the revolutionary discoveries of Hall and Héroult, much work had been accomplished by previous developments. In briefly tracing the development of aluminium, therefore, it is necessary to go further back—to the time when reasonably pure aluminium was produced in sufficient quantity to test some of its properties, just a century ago—and the author divides this time into three significant periods: Laboratory, commercial and industrial, and directs particular attention to the part played by Britain in the progress of this metal and its alloys.

ALTHOUGH aluminium is the most abundant *metallic* element in the solid portion of the earth's crust, of which it represents about 8%, it is never found in the free state, but mainly in combination with oxygen and silicon in the form of silicates such as feldspars, micas and clays. The high affinity of aluminium for oxygen makes its direct reduction by carbon impracticable, which explains why its commercial production had to await the advent of cheap electric power.

Early History

Some controversy has arisen over the exact date on which metallic aluminium was first produced, but it is now generally agreed that it was in 1845, or just 100 years ago, that the German scientist, Wöhler, at the University of Göttingen, first succeeded in producing metallic particles of sufficient size to recognise as aluminium, and in sufficient purity to measure some of its properties. The process which he used was the reduction of aluminium chloride with potassium, and some of the small pellets which he produced are preserved in a collection of the Göttingen University. The *laboratory* production of aluminium can, therefore, be considered to date from this time.

Paul Héroult, inventor of the electrolytic process.

Nine years later, in 1854, H. Sainte-Claire Deville improved upon Wöhler's process by using sodium instead of potassium, which not only reduced the cost, but the double chloride formed acted as a flux and allowed the aluminium globules to coalesce into pieces the size of marbles, which could be melted down afterwards and cast into ingots. The *commercial* production of aluminium can, therefore, be considered to date from this discovery.

In 1859, Sainte-Claire Deville published his classic book, "De l'Aluminium, ses Propriétés, sa Fabrication et ses Applications." and described his operations at Nantarre, where a mixture of aluminium - sodium chloride, fluorspar (flux) and metallic sodium were charged into the heated hearth of a reverberatory furnace. After the reaction had ceased the aluminium was tapped out of the furnace in a stream under the liquid slag. The purity of the metal produced by this process was about 97%, and the price about 200 francs per kilo, or some £8,000 per ton.

Electrolytic Process

No important improvements were made in this process until about 1885, when the Castner method of producing sodium out the cost of production of aluminium, which then sold at about 16/. per lb. or £1,800 per ton. Many variations of the sodium - reduction process were developed in various countries, but they were soon to be made completely obsolete by the electrolytic process invented almost simultaneously in France and America in 1886.

On April 23rd, 1886, Paul Héroult applied for his patent in France for the electrolytic production of aluminium; while on July 9th, of the same year, Charles Martin Hall made a very similar application for patent in the U.S.A. There is no evidence to suggest that either had any knowledge of the work being done by the other, and the simultaneous discovery was a pure coincidence, which is enhanced by the fact that both were born in 1863 and both died in 1914.

Both patents cover the electrolytic reduction of alumina dissolved in a bath of molten cryolite (double fluoride of sodium and aluminium), using carbon electrodes; and this is the process in use throughout the world to-day, so that the *industrial* production of aluminium can be stated to date from this time. Litigation between the two inventors regarding priority was avoided by an arrangement under which Hall obtained sole patent rights in America, while

Works at Patricroft, where first electrolytic aluminium was produced in Britain.

Héroult obtained the patents in other countries.

Paul Héroult was the son of a tanner and was studying to be a mining engineer when his father's death intervened and he took charge of his father's tannery. However, he pursued his metallurgical researches at home, and it was at home that he first produced aluminium electrolytically. He first used carbon electrodes, but afterwards experimented with copper ones and, to his surprise, produced aluminium-copper alloys, the first production of aluminium-bronze. There was at that time little interest for pure aluminium, but a good deal for the aluminium-bronze, which was found particularly good for ships' propellers, so at first Héroult concentrated his energies on developing the alloy process, which accounts for the fact that pure aluminium was not produced in France till about 1900.

Charles Martin Hall was the son of a Congregational minister in Ohio, who studied chemistry at Oberlin College. After graduating, he set to work to solve the problem which he had set himself, to reduce aluminium from its ores, and in nine months he had solved it.

He carried out a number of experiments to reduce the metal from clay by means of carbon at a high temperature, but they all failed, so he turned his attention to the electric current. After unsuccessful attempts to electrolyse aqueous solutions of aluminium he turned to anhydrous solvents, first trying fused fluorspar and magnesium fluoride, both of which melted at too high a temperature. Then he thought of cryolite, which had been used by Deville as a flux in reducing aluminium chloride with sodium and he found that it melted easily and dissolved alumina. He first used a clay crucible and two carbon electrodes, but the flux attacked the clay and the experiment was a failure. He then lined the crucible with carbon and was able to produce globules of aluminium.

Hall's process was first operated in 1887, by the Cowles Electric Smelting and Aluminium Co., who were making aluminium-bronze by a process similar to that of Héroult. But after about a year production ceased, as the market called for aluminium-bronze rather than pure aluminium, as in Europe. The next year it was taken up by a Captain Hunt and A. V. Davis, who formed the Pittsburgh Reduction Company, which afterwards became the Aluminium Company of America.

The first plant in Europe to produce pure aluminium by the electrolyte process was installed at Neuhausen, in Switzerland, in 1887 by the Soc. Métallurgique Suisse, which afterwards became the Aluminium-Industrie A.G., who acquired the patent rights for Europe. In 1889, the Société Electro-Métallurgique began operating the Héroult process at Froges, in France, and in 1894 the British Aluminium Co. acquired the rights for Great Britain. By 1900 the process had been developed to a point which enabled aluminium to be sold at about £150 per ton, and further improvement in detail gradually brought down the price to under £100 per ton before the war.

THE BRITISH INDUSTRY

The first commercial production of aluminium in England was made in 1860 by Bell Brothers at works which they had established at Newcastle-on-Tyne, using the same process as used at Nanterre by Deville. These works continued in operation until 1874, when they were closed. In 1886, a concern called the Aluminium Company Ltd. was started with works at Oldbury, near Birmingham, and in 1889 the Alliance Aluminium Co. Ltd. opened works at Wallsend-on-Tyne, all using the same basic process of reduction of the double chloride with sodium, using cryolite as a flux.

An important advance was made in 1885, when the Cowles Syndicate put down works at Milton, near Stoke-on-Trent, to operate the Cowles electrolytic process for the production of aluminium-bronze. Some discussion has taken place as to whether the Cowles process could produce pure aluminium; it is fairly certain that it never did, at any rate in this country.

In 1890, a concern called the Metal Reduction Syndicate was formed to "demonstrate" the Hall process in England, and works were put down at Patricroft, near Manchester, with an output of about 4 tons per day. These small works were, therefore, the first to produce aluminium electrolytically in this country, and were closed down in 1894.

The British Aluminium Co. Ltd.

The British Aluminium Company was founded in 1894 to acquire the patent rights for the Bayer process of producing pure alumina and the rights for U.K. and Dominions (except Canada) for the Héroult Aluminium Reduction Process. It also acquired Bauxite mines in Northern Ireland and potential water power rights in North Wales. Lord Kelvin was appointed technical adviser and joined the Board four years later and remained a director till his death in 1907, being then joint technical adviser with Mr. Morrison, now Sir Murray Morrison, managing director.

The original share capital was £300,000, of which £100,000 was in Ordinary Shares and £200,000 in Preference Shares, most of which went in the acquisition of the patents. Progressive increases in capital were made to finance the various developments, until it now stands at £8,000,000, of which £3,000,000 is in Ordinary Shares, £1,500,000 in Preference Shares and £3,500,000 in Debentures. At the end of 1943 the published reserves were

approximately £5,500,000 and the balance sheet total over £17,000,000. The company paid its first dividend of 5% in 1913, and dividends have been paid regularly ever since, the highest being 12½%, and the average in recent years 10%.

The operations of the company fall naturally into three stages carried out at three different kinds of works, namely :

Alumina Works, where the bauxite is treated for the recovery of its alumina content, and situated where coal is cheap and with good port facilities for the unloading of the bauxite boats.

Reduction Works, where the pure alumina is reduced in the electric furnace to metallic aluminium and situated where electric power is cheap, which usually means water power.

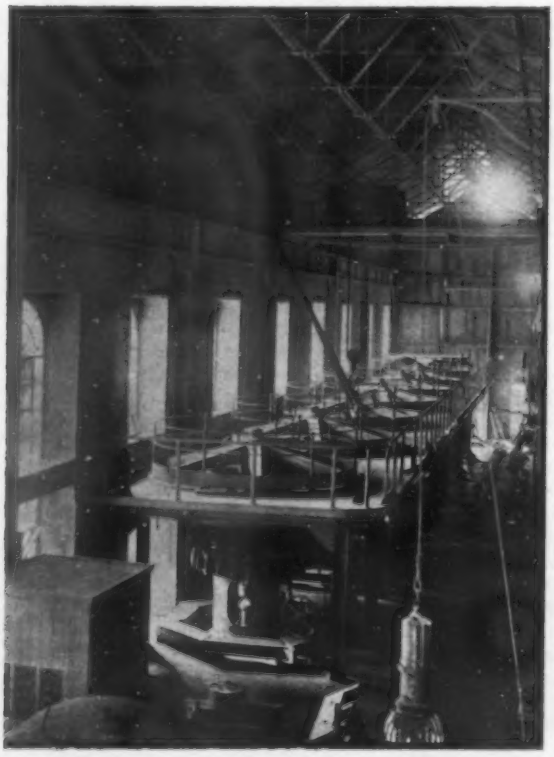
Fabricating Works, where the metal, in either pure or alloyed form, is fabricated into sheet, tube, sections, and the many other forms in which it is supplied to the consuming industries.

Alumina Works

Although it was originally intended to use Irish bauxite and the first alumina works were put down at Larne for that purpose, it was found that the local ore was too low in alumina, and mines were acquired in France and subsequently in other parts of the world. The Larne works started production at the end of 1896. In 1913, work was started on new alumina works at Burntisland, in Scotland, which were completed in 1917, and finally, a third alumina works was put down at Newport, Monmouthshire, which started production in 1939.

In addition to its use for reduction to metallic aluminium, alumina in various forms is used in many industries, and special grades are produced to meet these requirements.

Power Station at Foyers, where the British Aluminium Co. first produced aluminium in 1896.



Cryolite, pure and impure.

Reduction Works

The original project for water power development in North Wales was dropped, and the first reduction works, at Foyers, in Scotland, were completed in 1896, but the small demand at that time could not absorb the whole output and part of the power was used for other purposes, chiefly calcium carbide. The company had to erect houses and build a village to accommodate the staff and workmen.

By 1904 the demand exceeded the capacity of the Foyers works and construction of the works at Kinlochleven, at the head of Loch Leven, was started in 1905, and a temporary factory commenced operations in 1907, followed by the permanent factory in 1909. Again, a complete village and staff houses had to be built and, later, a road to connect Kinlochleven with Ballachulich, the only previous connection being by boat on the loch.

The company were the pioneers of the production of aluminium in Norway, as in Great Britain, and the works at Stangfjord were opened in 1908, and the works at Vigelands in 1912.

During the last war Sir Murray Morrison conceived the Lochaber project, but opposition in Parliament prevented the passage of the necessary legislation till 1921, and work was commenced in 1924. Lochaber produced its first metal in 1929, further extensions were carried out in 1938, and the last stage was completed during the present war.

The company have spent more than £8,000,000 on these three reduction works in Scotland, and they own some 130,000 acres in the Highlands.

Fabricating Works

When the company was formed, they acquired the Milton, Staffs., works of the old Cowles Syndicate, where

aluminium-bronze was produced by the Cowles electrolytic process and cast into ships' propellers, chiefly. There was also a small rolling plant and this was extended and the old rope drive from horizontal engines gradually replaced by electric motors. Later on the works were considerably extended to produce wire, extrusions, etc., and have since been still further enlarged and the fabrication of heat-treated alloys undertaken.

Further fabrication facilities were acquired by the starting up of the Warrington works in 1914, where strip-rolling was specialised in, and later extrusion, both of pure metal and alloy. In order to help further in the fabrication of the enormous quantity of sheet required, mainly for aircraft construction, the company designed, erected and are now managing, on behalf of M.A.P., the largest and most up-to-date rolling mill in Britain, "somewhere in Scotland." This factory is not completed yet, but it started production in June, 1944, and is expected to play a very important part in post-war developments in the aluminium industry.

In addition to these main works, the company hold a controlling interest in eighteen subsidiaries, and minority interests in sixteen associated concerns, which either supply raw materials or further treat some of the company's products.

Aluminium Corporation

In 1908 the Aluminium Corporation Ltd. put down small reduction works at Dolgarrog, North Wales, and a rolling mill was added at a later date, both taking power from the North Wales Power Co. The alumina for these works came from the alumina works of their associated company, the International Aluminium Company, at Hebburn-on-Tyne, which also owns a reduction works at Glomfjord, in Norway.

During the present war, additional productive capacity for aluminium has been installed, but details must await the end of hostilities, and in any case the works were largely of a temporary character to meet an urgent demand, using existing sources of power supply.

Milestones of the Aluminium Industry

Year. *Event.*

1845—Wöhler, in Germany. First Laboratory Production.
1852—Deville, in France. First Commercial Production.
1860—Bell Brothers. First production in England.
1885—Héroult and Hall. Invention of Electrolytic Production.
1888—First Electrolytic Production in U.S.A.
1889—First Electrolytic Production in Switzerland.
1890—First Electrolytic Production in England.
1890—World output reaches 5,000 tons.
1894—Formation of British Aluminium Co.
1896—First metal produced at Foyers.
1908—Discovery of Duralumin by Wilm, in Germany.
1909—Kinlochleven works completed.

Bauxite mines in the South of France.

1929—First metal produced at Lochaber.
1941—World output reaches 1 million tons.
1943—World output exceeds 2 million tons.

MODERN METHODS OF PRODUCTION

Fundamentally, the processes in use to-day in the chief producing countries are the same as when first developed, though the details of the plant have, of course, undergone progressive improvements and production units have steadily increased in size, leading to greater efficiency.

Bauxite, which is widely distributed throughout the world, is almost exclusively used as the source of alumina, and the classic Bayer process of recovery still holds its own in spite of all attempts to find something better. This process involves the treatment in an autoclave under pressure and high temperatures, of ground bauxite with caustic soda solution to form a strong alumina-rich sodium aluminate solution, with a residue containing the unattacked impurities. After filtering to remove the impurities the sodium aluminate solution is diluted and run into decomposers where most of the alumina is precipitated as hydrate under carefully controlled conditions and the soda-rich liquor returned to process to dissolve more alumina.

The hydrate of alumina from the decomposers is washed and filtered to remove as much soda as possible, which is returned to process, and the hydrate is then calcined at a high temperature, above 1,000° C., in large rotary furnaces, which not only removes the three molecules of combined water, but converts the alumina into the non-hydroscopic or alpha form, which low-temperature calcination fails to do.

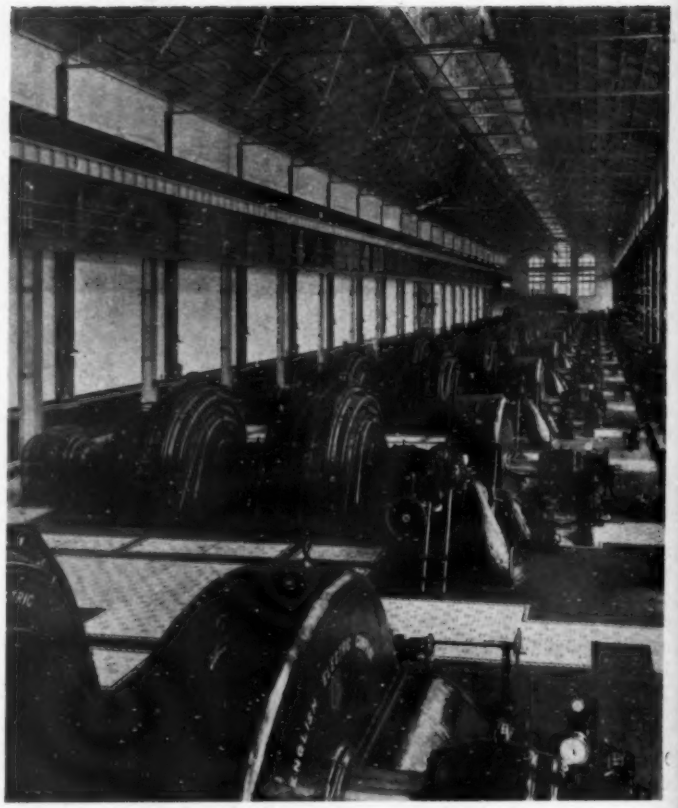
The modern reduction furnace is a round or rectangular steel box, lined with carbon, which acts as the cathode. Carbon anodes are suspended from supports above the furnace, or in the latest practice, the Söders berg, self-baking electrodes are used. The bath consist- of a solution of alumina in molten cryolite, and the voltages per cell is 5–7 volts, being adjusted so that only the alumina is decomposed and the cryolite

remains unattacked, additional alumina being added to the top of the furnace at intervals as reduction proceeds. The oxygen in the alumina combines with the carbon of the anodes to form in the final stage carbon dioxide, which escapes to atmosphere while the aluminium released falls to the bottom of the furnace and is tapped at intervals.

The carbon required to reduce aluminium oxide to aluminium is supplied by the material of the anode electrodes which are, therefore, consumed and any impurities in the raw materials may find their way into the metal. Most aluminium producers have their own carbon factories where the electrodes are made from high-quality, low-ash coke, with tar or pitch as a binder. In 1923, the Söderberg self-baking electrode was patented and this is now more or less standard practice in the larger types of furnaces.

The Söderberg electrode consists of a cylinder or rectangular metal casing extending from the furnace to a platform above the furnace. This is kept filled with unfired electrode paste which is slowly baked at its lower end by the heat from the furnace, as well as by the current passing through the casing, until it has become sufficiently baked to carry the current itself. As the electrode is consumed, so the casing is lowered at intervals, and new sections of casing added as required.

Natural cryolite (sodium-aluminium fluoride) is found in only one place, Greenland, but it can be produced synthetically from soda, alumina and hydrofluoric acid, and most of the aluminium producers have such plants, if only as a safeguard against stoppage of supplies. Although, in theory, the cryolite is not attacked, in practice there is a certain consumption of cryolite, the aluminium fluoride radical being normally preferentially consumed, so that pure aluminum fluoride must be added as make-up in addition to cryolite.



Power Station at Lochaber (compare with Foyers in 1896).

Aluminium Alloys

In the early days of the industry other metals, chiefly copper and zinc, were added to pure aluminium to improve its physical and mechanical properties, particularly in the cast state. Pure metal was used almost exclusively for sheet, tubes and sections, the additiona strength required being secured by cold working. When the writer, in 1908, ventured the opinion that the future of aluminium lay in the field of alloys he was laughed at by many, but to-day light alloys hold the stage, and the use of unalloyed aluminium is more or less confined to chemical plant and electrical conductors.

Most metals and alloys can be caused to take up the shape desired by either liquid flow in the shape of castings or plastic flow in the shape of rolled, drawn, pressed or extruded forms. The addition of other metals to pure aluminium has the two-fold object of improving the

WORLD PRODUCTION OF ALUMINIUM, IN THOUSAND TONS.

Country	1900	1905	1910	1915	1920	1925	1930	1932	1934	1936	1938	1940*	1943*
France	—	—	6·0	6·0	12·0	20·0	26·0	14·5	16·0	26·5	45·0	50·0	60·0
Switzerland	—	—	10·0	12·5	13·0	22·0	20·5	8·5	8·5	14·0	27·0	30·0	30·0
Germany and Austria	—	—	4·5	4·5	12·0	29·0	33·5	21·0	39·0	100·0	165·5	245·0	350·0
Norway	—	—	1·0	3·5	5·0	22·0	27·5	18·0	15·5	15·5	30·0	25·0	25·0
Great Britain	—	—	5·5	6·0	8·0	15·0	15·0	10·5	13·0	16·5	23·5	32·0	50·0
Russia	—	—	—	—	—	—	—	1·0	14·5	38·0	45·0	60·0	100·0
Other European	—	—	—	—	—	2·0	8·5	14·5	14·5	19·5	31·5	41·0	60·0
Europe	—	—	27·0	32·5	50·0	110·0	131·0	88·0	121·0	230·0	367·5	483·0	675·0
U.S. America	—	—	17·5	45·0	90·0	62·0	104·0	47·5	33·5	102·0	130·0	187·0	900·0
Canada	—	—	4·5	8·5	10·0	8·0	35·0	18·0	15·5	26·0	66·0	95·0	450·0
America	—	—	22·0	53·5	100·0	70·0	139·0	65·5	49·0	128·0	196·0	282·0	1350·0
Japan	—	—	—	—	—	—	—	—	0·5	7·5	17·0	32·0	100·0
World	5·0	11·2	49·0	86·0	149·0	180·0	270·0	153·5	170·5	365·5	580·0	797·0	2125·0

* Estimated.

casting or fabricating characteristics and of enhancing the physical and mechanical properties of the finished article. Alloys suitable for casting are, in general, not well adapted for rolling or extruding, so that they naturally fall into two main groups, with subsidiary groups as follows :—

(i) *Casting Alloys.*—Sand-casting, chill-casting and die-casting, each sub-divided into non-heat-treatable and heat-treatable.

(ii) *Wrought Alloys.—Work - hardened*, containing small additions of other metals and, in general, non-heat-treatable.

(iii) *Medium strength*, containing higher proportions of alloying elements, but without heat-treatment.

(iv) *Strong Alloys*, which rely for their properties upon some form of heat-treatment.

Heat-Treatment

The discovery of the heat-treated alloys by Wilm in 1908 was another milestone in the history of the metal, and it is a remarkable fact that until quite recently the basic composition of the original Duralumin remained substantially the same, and its heat-treatment almost identical with that laid down in Wilm's original patent. The Dürener Metallwerk in Germany developed the invention and the rights for this country were acquired by Vickers and exploited by their subsidiary James Booth and Son, who also acquired the registered trade marks, " Duralumin " and " Dural." The composition of the original Duralumin was 4% copper and 0·5% each of manganese and magnesium, and the value of nickel additions for improving the high-temperature properties was first discovered by work carried out at the National Physical Laboratory, which culminated in the development of the well-known " Y " alloy, containing nickel and capable of heat-treatment in the cast state. During the years 1907–1921, a systematic research into light alloys was carried out at the National Physical Laboratory, Teddington, under the auspices of the Alloys Research Committee of the Institution of Mechanical Engineers, the main results being published in four reports as follows :—

1907—Eighth Report—Aluminium and Copper.
1910—Ninth Report—Aluminium, Copper and Manganese.
1912—Tenth Report—Aluminium and Zinc.
1921—Eleventh Report.—Some Alloys of Aluminium

These reports cover, perhaps, the most systematic and fundamental research into light alloys ever undertaken in any country ; and the eleventh report, by Rosenhain, Archbutt and Hanson, paved the way to the intensive development work later carried out in the laboratories of the leading firms in the alloy field.

A discovery of far-reaching importance in the field of casting alloys was that of Pacz who, about 1922, showed the grain refining effect of the addition of sodium to high silicon alloys, resulting in an alloy with remarkable casting properties, with a fracture similar to that of a forging, and with much improved strength and ductility. We at last had really malleable light alloys, easy to cast in thin and intricate shapes. Lighter than aluminium itself and highly resistant to corrosion. Whereas, previously, silicon was looked upon as an undesirable impurity in aluminium, it became an alloying medium of the first rank. This type of alloy, containing up to 13% silicon, with or without other minor additions, still remains one of the most important engineering light-casting alloys. A variation of this alloy containing small additions of nickel, copper and magnesium, and known as " Loex," has a wide use for pistons, particularly the large size used in Diesels, owing to its low coefficient of expansion.

The next milestone in the alloy field was perhaps the work carried out by Hall and Bradbury in the Rolls-Royce laboratories in the years 1926-1930, resulting in the development of the now famous RR series of high-strength cast and wrought alloys, most of them amenable to heat-treatment. The technical and commercial development of this series of alloys was taken over by High Duty Alloys Ltd., and marketed under the name of " Hiduminium." The wrought series of alloys, with varying and fairly complicated compositions, are characterised by their excellent hot-working properties and the Rolls-Royce Merlin series of engines owe much to them.

The original Duralumin type of alloy was "tempered" by being heated to about 500° C., quenched in cold water or oil, and aged at room temperatures. The more recently developed strong alloys are " artificially " aged by being subjected to a subsequent " precipitation " treatment for 12–24 hours at 150–200° C., before quenching in water or cooling in air.

The year 1930 saw the birth of the aluminium-magnesium class of alloy, containing 5–10% magnesium, with or without other small additions, marketed under the names of Hydronalium, M.G.7, Birmabright, etc. Up to this time the only wrought structural light alloys, combining high strength with good ductility, owed those properties to some form of heat-treatment, whether in the cast or worked condition. Such alloys can only be worked in the annealed condition or immediately following quenching and must always be heat-treated after any appreciable hot- or cold-work has been done on them, if they are to retian their high mechanical properties unimpaired.

These considerations have led to the development of a number of structural light alloys with fairly high strengths and reasonably good elongation, obtained partly through cold-work instead of heat-treatment. Such alloys cannot quite compete on a strictly strength/weight basis with the best of the heat-treatable alloys, but they are likely to meet more nearly the demands of the transport industry, other than aircraft, and further developments may be expected in the post-war period.

During the present war new alloys have been developed to meet the demands of fighter aircraft for higher strength/weight ratios and a certain amount has been published in the States about developments on that side, but in other countries less has been made public and it therefore seems better to wait until the whole story can be told and the contribution of research on this side better assessed.

THE ELECTRO-MAGNETIC SPECTRUM IN ANALYSIS.

In a review of methods which apply the electromagnetic spectrum to analysis,* the reason for the possibility of such application is described; The sphere of each method is outlined and illustrated by examples while a number of references permit the subject to be followed further.

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* Gans, *J. Chem. Educ.*, 1944, **21**, 421.

Development of Aluminium Alloy Forgings and Stampings

By J. Towns Robinson

Technical Superintendent, High Duty Alloys, Ltd.

From a laboratory curiosity of a century ago, aluminium is applied to such wide and varied purposes that it now ranks in the world's tonnage of metals. By careful study of the physical and mechanical properties of this metal and its alloys and by the gradual development of manipulative techniques, phenomenal progress has been achieved. For some time production has been mainly confined to the requirements of the Services, but, soon this progressive industry will be available to contribute to the needs of other industries for reconstruction. Of the manipulative processes that have assisted in increasing the usefulness of aluminium alloys, not the least important are forging and stamping, and in this article the author briefly surveys progress in this field up to the present high standard of production.

LESS than a century ago aluminium alloy forgings and stampings were unknown, although the base metal—aluminium—first produced in 1845 and exhibited in massive form in 1855*, was worked into wrought forms, chiefly by rolling and hammering, as far back as 1890. Emperor Napoleon III of France was the first to realise the potentialities of this newly discovered light metal and to forsee the advantages of its use for military equipment and armour. He therefore provided the necessary funds to enable Henri Sainte-Claire Deville to undertake the manufacture of aluminium. As events have shown, the Emperor's martial visions were too far ahead of their time to be fulfilled in his lifetime. A great deal of knowledge and experience had to be accumulated, and many new processes devised, before they were realised.

At first the progress of aluminium was, by modern standards, slow and although pure aluminium in wrought forms found many uses, its use in engineering was restricted by its softness and low strength. However, the efforts of research workers were eventually crowned with success by the development of alloys with copper, silicon, magnesium and other elements which greatly improved the mechanical strength. The advent of the heat-treated strong alloys starting with the discovery of the age-hardening phenomenon by Alfred Wilm† in Germany in 1909 and his development of "Duralumin" produced far-reaching effects and laid the foundation of what was to become a large and flourishing new industry.

The "Duralumin" type alloys found their first extensive application in the construction of the Zepplin airships employed by Germany in the world war (1914-1918). These light alloys, mainly in the form of sections, were used in comparatively large quantities in the main structures of these dirigibles. Thus the first world war was responsible for the very rapid development of strong light alloys in the course of which, from a soft and ductile metal were developed alloys with mechanical properties equivalent to those of mild steel.

Another line of alloy research which, starting somewhat later than Wilm's work, did not find actual application during the war, was that devoted chiefly to the development of aluminium-copper-zinc, and aluminium-copper-nickel-magnesium alloys. The studious and diligent work on these alloys carried out by the late Dr. Rosenhain and his colleagues was not published in full until 1921,‡ when it was revealed that development of the ternary alloys of aluminium with copper and zinc had been abandoned in view of the remarkable properties exhibited by the aluminium copper-nickel-magnesium alloy which came to be known as "Y" alloy.

"Y" alloy was found to combine mechanical properties equal to those of "Duralumin" with superior strength at elevated temperatures. Like those of "Duralumin," these properties could be improved by working and heat-treatment as was shown by the successful rolling and forging experiments carried out jointly by the Royal Airship Works, Cardington, and the N.P.L. as early as 1911-1913. It became apparent that this alloy and "Duralumin,"—the one for engine parts and pistons in particular and the other for structural parts—were destined to play a very important part in the future of the light alloy industry and in aircraft engineering.

In the 1914-1918 period the limitations of materials were already recognised as being among the chief obstacles to the progress of aero-engine development along the lines of increased power/weight ratios and dependability. Among the principal limiting factors in the early days were the properties of cast aluminium alloy pistons. The strength of these pistons under increasingly severe service conditions left much to be desired, and they lacked, moreover, the uniform soundness necessary for dependability. The development of a technique for the large scale production of forged "Y" alloy pistons became an urgent necessity since it was known that in the wrought form this material possessed the desired qualities such as uniformly high strength at elevated temperatures, lightness, good thermal conductivity and friction properties.

At this stage, in order to ensure the rapid development of full scale manufacturing methods, the work was handed over to commercial enterprise, but able and valuable advice and assistance continued to be given freely by the N.P.L.

In the early twenties, the piston forging consisted of a plain cylindrical cheese made simply by upsetting a

* In 1855, at the Paris Exposition, a bar of pure Aluminium was exhibited. See: "De L'Aluminium: Ses Propriétés, sa Fabrication et ses Applications," by Henri Sainte-Claire Deville. Published, 1895.

† 11th Report of the Alloys Research Committee.

‡ Wilm's results were published in "Duralumin Heat Treatment."

Battery of drop hammers—capacity from 1 to 3 tons, on the production of piston stampings.

chill cast billet. The piston was machined from this solid cheese with, of course, a very high metal loss. The grain flow produced by this process also left much to be desired. The grain size could be so controlled as to give a very fine structure but the pronounced orientation to which we are accustomed to-day was lacking.

Typical of the mechanical properties of pistons produced by this early technique are those of the "Jaguar" engine pistons, having a yield-point of 15 to 18 tons per sq. in., an ultimate tensile strength of 23 to 26 tons per sq. in. and an elongation of 10 to 15%. Such properties represented a very considerable increase over those obtained from cast pistons.

The introduction of these forged pistons also gave considerable impetus to the development of other well-known aero-engines, while pistons of considerably larger size, also machined from solid forged blanks, were successfully used in Diesel engines. "Y" alloy connecting-rod stampings were used with success in some aero-engines, while "Duralumin" forgings also found many and varied uses, each wrought alloy finding its well defined spheres of application.

The early days of the working and forging of light alloys were filled with difficulties and disappointments and many were the problems which had to be overcome, but overcome they were by the resourcefulness, the unbounded energy and the enthusiasm of those engaged upon the task. It was the beginning of a new science and a new technique, with no past experience to fall back on. Consider, for instance, the personnel and the plant and equipment available for the work. The former were steeped in the traditions of the older industry, the working of iron and steel, which had evolved gradually over a very long period of years. The latter had been designed to operate under certain defined conditions which were very far removed from those encountered in the working of aluminium alloys. The new technique had to be built up, and the equipment modified, step by step as practical experience in the working of the alloys was accumulated. The lower and far narrower range of temperature for the working of light alloys compared with steel presented many problems, and uncertainties which seem trivial to-day, but which, in those days, meant all the difference between success and failure.

The lack of suitable furnaces both for working and heat-treatment was a serious handicap. Electric furnaces designed for the ferrous alloys were unsatisfactory for heating the light alloys owing to imperfect control at the lower operating temperatures required; and much scrap resulted from their use. With no visible indication of temperature to act as a guide, pyrometric control was essential, but here again existing equipment, designed as it was for higher temperatures, left much to be desired.

It was in meeting these early difficulties that the salt bath played its most important role, and in spite of certain obvious disadvantages this method of heating still finds important uses to-day.

Forging and stamping equipment, although more readily adaptable to the requirements of light alloy working than was the heating equipment, nevertheless was far from ideal for the purpose, since neither the weight of the hammers nor the rigidity of the guides were adequate. Steel is relatively soft and freely workable at the forging temperature, while aluminium alloys, due to their complex constitution, require a considerably greater amount of energy to impart the degree of deformation necessary for optimum properties to be obtained.

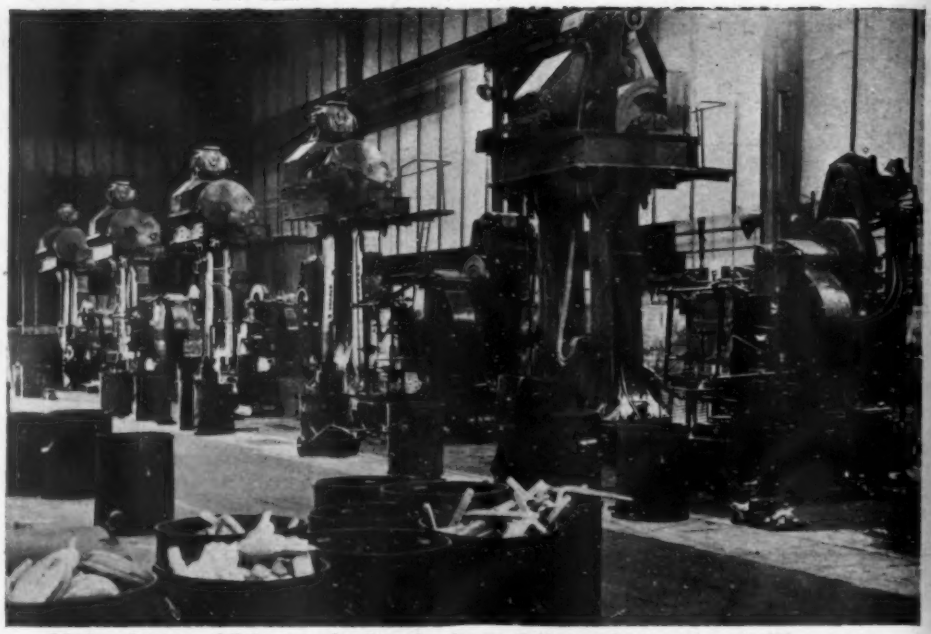
After the development of "Duralumin" and "Y" alloy no very important developments in the way of improved alloy compositions were evolved for some time. Preoccupation with the difficulties of developing manufacturing techniques probably absorbed all the energies and thoughts of those concerned, and it no doubt took some time for engineering developments to exploit their properties to the full. During this brief lull these two alloys, each in its particular sphere, retained unchallenged supremacy.

By 1927, however, the engineers had caught up again and the need for improved materials became once more a matter or urgency. This necessity was thrown into high relief by the international race to develop high performance aircraft engines for the Schnieder Trophy contests of 1929-1931. The minds of designers and engineers were sharply focused on the potentialities of strong light components of wrought aluminium alloys. The older casting alloys had made their great contribution to aeronautical progress but the limit of their strength had been reached. Higher strength and increased uniformity and reliability became the urgent requirements for the highly stressed components then visualised.

It was as a direct response to these new demands for high performance that alloy research was intensified. In a surprisingly short interval of time this resulted in the development by Messrs. Hall and Bradbury, in 1927—primarily for the Rolls Royce "R" engines—of the RR range of cast- and wrought-alloys, and in their subsequent large-scale manufacture, commencing in 1930, as the well known "Hiduminium RR" series of alloys. The greatly improved properties made available by the advent of these alloys, together with the concurrent rapid growth of the knowledge of their

properties and technology were quickly utilised by aircraft designers and constructors.

Within a remarkably brief period the new alloys were being forged into a wide variety of highly stressed aero-engine components such as radial-engine crankcases, cylinder heads, cylinder barrels, super-charger rotors, etc., and, of course, the pistons and connecting rods already mentioned. These and many other forged light alloy components, previously deemed impossible of manufacture by the forging process to give the strength and other properties required by the designer, were very soon in production on a scale which in those days seemed very large indeed.



Modern battery of light capacity drop forgings. Self-contained motor device, making each hammer an independent unit.

Chambersburg drop hammer operating on radial engine crankcase stampings. Capacity 35,000 lb.

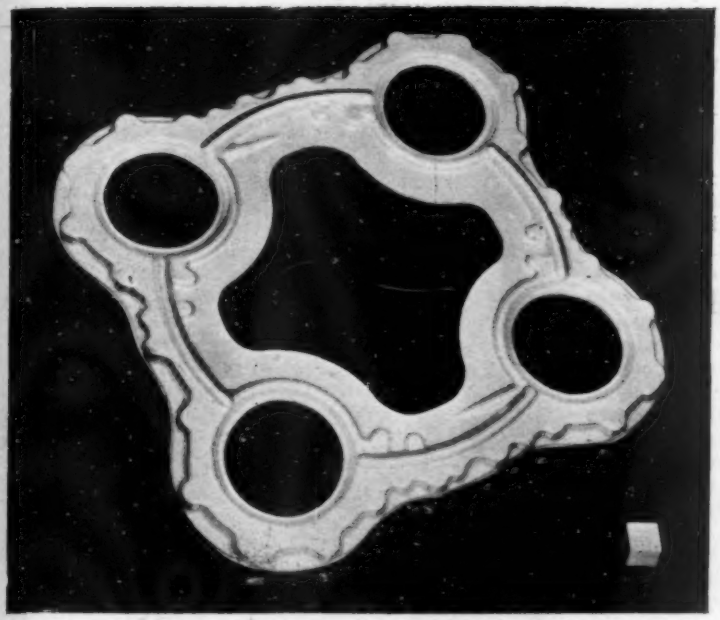
These new alloys possessed good working properties and were comparatively easy to manipulate, but the rapidly increasing scale of manufacture naturally placed a considerable strain on the available plant and again directed attention to the need for more powerful equipment and tools.

The next decade, up to 1939, witnessed a tremendous growth in the uses of light alloy forgings and stampings and vast improvements in their properties and quality were achieved in response to the demand created by the rapid increase in the power of aero-engines during this period.

A line of development along which considerable progress has been made in recent years is the modification of the old "Duralumin" composition to yield a variety of alloys of greatly improved mechanical properties. Thus we have two principal types of wrought aluminium alloys—the "Duralumin" and the "Hiduminium RR" types—between they giving a very wide range of physical and mechanical properties for the engineer to choose from. Behind them we have amassed a tremendous store of knowledge of their manufacture and characteristics.

As has already been mentioned above, developments in plant and equipment have also played a very important part in the attainment of the present high standard of light alloy forgings. These developments may be seen to-day in the many well laid out shops now producing the vast quantities of forgings, pressings, etc., demanded by our aircraft programme.

In the early days the drop hammers and presses available to the stampers were of very limited capacity so that forging had to be carried out in a relatively large number of steps with repeated reheatings to restore the working temperature. Nowadays the power and weight of presses and hammers have been greatly increased so that the forging operations are carried out in a fraction of the time previously required. The different functions



Reduction gear carrier-plate stamping in Hiduminium RR.56.

of drop hammer and press have not altered materially but greater power and mechanisation of the production line have been the principal factors in the great improvements achieved.

The old drop-stamper very often worked with improvised tools which he himself had "knocked up." To-day he has at his disposal the full resources of specialised machinery and the skill and art of the tool maker, while the job is planned by experts in both its mechanical and metallurgical aspects. There is still one branch in which the skill of the forger remains of supreme importance, and that is in the preparation of the "dummy" prior to stamping. For complicated stampings this preliminary work is carried out by hand manipulation under the forging hammer, and although the operator is provided with templates to work to, the forming of the dummy to the contours of the stamping die calls for the highest degree of skill and accuracy of working. This operation is of the utmost importance since it is the one which principally determines the ultimate properties of the stamping.

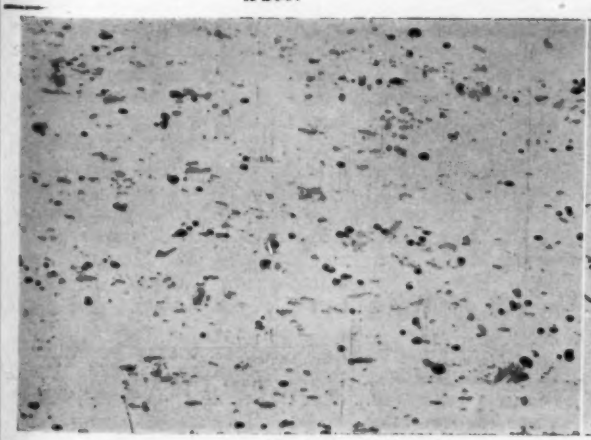
Multiple tooling, particularly in press work, has reached a high degree of perfection. Compared with the old piston, machined from a solid forged cheese, the modern pressed piston, close-forged to finished dimensions requires a very small amount of machining. Apart from the obvious economies in material and labour thus effected, this type of forging gives considerable improvements from the metallurgical point of view.

Probably no branch of the fabrication of aluminium alloys has seen more development in recent years than the technique of heat-treatment. In the past, lack of knowledge and of proper industrial equipment made this operation the one most open to abuse. That heat-treatment is now a highly developed science is due to intensive metallographic research on the constitution and structure of the alloys and to co-operation between engineer and metallurgist. During the present war a considerable amount of experience has been accumulated as a result of this collaboration, with results which are clearly reflected in the quality of light alloy components and in the machines in which they are used.

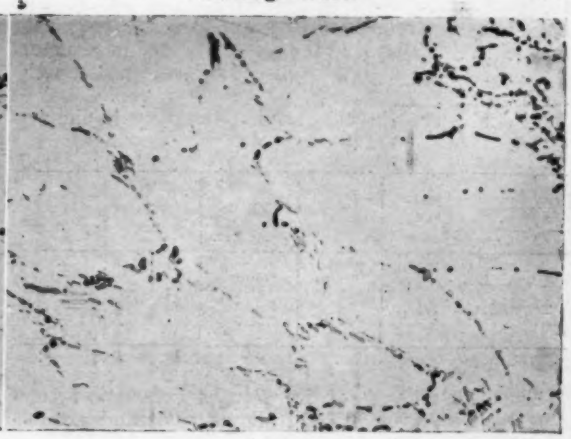
The days of the salt bath, with the manhandling of each individual part, are gone. In its place we now find highly efficient furnaces, controllable to plus or minus two degrees centigrade, in which the whole cycle of operations is continuous and automatic. The use of such specialised equipment not only ensures that each forging receives exactly uniform treatment, but it also permits the achievement of the highest rates of production with a minimum of cost.

The control of quenching stresses has now been accomplished by the development of X-Ray crystallographic

Typical micro-structure of well-worked RR.59 alloy, showing uniform constituent particle distribution. x 200.



A coarse net-work structure and large particle size which has not been completely broken down by working. x 200.



methods almost to the state of a routine test. The physical properties expected from light-alloy stampings are naturally higher to-day than ever before, and this standard is being regularly maintained. Not very long ago a figure of 25 tons per sq. in. ultimate tensile strength from actual stampings was considered to be fairly good. To-day this figure has been increased to 30 to 35 tons with an 0·1% proof stress of 27 tons per sq. in. A 10-ton increase in strength may not sound a great deal but it represents a 40% improvement which, measured in terms of the effort required to bring it about, represents a very considerable achievement.

Actual tensile strength, however important, is only one of the many essential features of a high quality light-alloy stamping. Too often good mechanical properties have been obtained in the longitudinal direction, while those in the transverse direction have been disappointingly low. Good grain flow, homogeneous crystal grain-size and particle distribution of the constituents are all factors which must be correlated with strength. These factors alone have caused many worries in the past, but they are now thoroughly understood and controllable.

The recently introduced alloy "DTD.364A," which is a development of the old dural composition, and the aluminium - copper - magnesium - manganese - zinc alloy "DTD.363A," are known to possess very attractive tensile properties in the form of extruded sections and bars—over 30 tons in the former and over 38 tons in the latter—but until very recently, due to difficulties in working, these high figures have not been reproduced in forgings and stampings. It is now possible, however, to produce—under carefully controlled conditions—stampings in the "DTD.364A" alloy with the following properties in the actual stampings :—

26 tons per sq. in. 0·1% Proof Stress.
30 tons per sq. in. Ultimate Stress.
8% Elongation.

Another important stage in the progress of alloy development which has resulted from several years' research is to be seen in the recent developments in the well-known "Hiduminium RR77" composition previously covered by Specification "DTD.363A." This alloy has now been modified to enable it to be produced in the form of forgings by normal production methods and yet retain its unparalled mechanical properties. In this work many difficulties have been encountered, to be solved step by step as the complex characteristics of this aluminium-copper-manganese-magnesium-zinc alloy have been resolved. The identification of the compounds formed in this alloy and the explanation of its structure by the metallographer represent a most praiseworthy achievement.

Typical properties taken from stampings in the new alloys are as follows :—

	0·1% Proof Stress Tons/sq. in.	Ultimate Stress Tons/sq. in.	Elongation % on 2 in.	Brinell Hardness
Longitudinal	27·7 to 31·5	32·0 to 34·0	12 to 17	145 to 150
Transverse	29·7 to 30·7	32·5 to 34·0	8 to 13	

This range of figures was taken from 18 test pieces from the same stamping.

Thus this alloy, in all its wrought forms has become the strongest wrought light alloy now available.

Tail wheel fork stamping in Hiduminium RR.56.

It is hoped that this brief history of developments in the forging of aluminium alloys may serve to illustrate the constant progress that has been, and is still being made in light alloy technology and that this progress is in no small part due to the constant zeal of all those engaged in this young industry, guided and tempered by strict adherence to the principles and methods of science.

Inauguration of the South Wales Branch of the Institute of Physics

PHYSICISTS employed in industry in South Wales and the surrounding district have for some time felt the need of local opportunities for the interchange of knowledge and experience of Applied Physics. At their request the Board of the Institute of Physics has, therefore, authorised the formation of a South Wales Branch of the Institute which is to be centred on Swansea.

The inaugural meeting of the Branch will take place at 2-30 p.m., on Saturday, March 10, in the Physics Department of University College, Swansea (Singleton Park), when Dr. C. Sykes, F.Inst.P., F.R.S., a member of the Board of the Institute and Principal of the Brown-Firth Research Laboratories, Sheffield, will deliver an illustrated lecture on "Physics in Metallurgy." Visitors will be welcome ; admission is free and without ticket.

Further particulars of the Branch may be obtained from the acting honorary secretary, Dr. T. V. I. Starkey, A.Inst.P., The Technical College, Mount Pleasant, Swansea.

The War-Time Aluminium Foundry

By George Mortimer

The British Aluminium Co. Ltd.

As aluminium became commercially available and was applied to engineering, it soon became evident that it was too soft for many engineering purposes and aluminium alloys began to appear. Initially these were used for castings and although development was slow in applying these new alloys, the motor car and, more recently, the aeroplane have given a tremendous impetus to development, as this brief survey of war-time progress clearly shows.

THE production of parts by pouring molten metals into moulds is one of the eldest of all the arts, and it long depended largely on individual skill and craftsmanship. Only within the memory of many of us has this ancient art been brought within the realm of science, more particularly under the stress of two great wars.

In the South African War aluminium itself was in its infancy, and attained no military significance whatever. During the period 1914-18 the metal became a munition of war of the first importance, and apart from fabricated forms it met the need for large tonnages of light castings, for transport, gun components, and the new but rapidly expanding weapon of aircraft. The cast alloys of those days, adequate as they were for the relatively modest duties then called for, were largely the result of rule of thumb and individual founder's preference. Pyrometry was in its infancy; X-Ray examination hardly heard of outside Government laboratories; analysis followed well-beaten, reliable, but somewhat ponderous chemical paths.

The need at that time for some co-ordination of available casting alloys led to useful work by Professor Lea and others, and to the well-known "L" specifications, L5, L11, L8, etc. The need for something better than these, especially for aero engine pistons, led to the work of the National Physical Laboratory, under the late Dr. Walter Rosenhain, culminating in the Eleventh Report to the Alloys Research Committee. That report gave us "Y" alloy, and wth it the application of heat-treatment to light alloy castings. It is probably the first light casting alloy to be developed by scientists from scientific fundamental data for a definite scientific end, and it may be regarded as a prototype for much subsequent development in this field.

The inter-war years saw many advances in light alloy metallurgy and control. The modified silicon alloys were discovered and developed by Aladar Pacz. The Rolls Royce laboratories produced their famous range of RR alloys, a scientifically modified version of "Y" alloy, "Birmabright," was developed, and confounded critics who associated the alloys of aluminium with inevitable doom when used in contact with sea-water. "Loex" came to life, offering low expansion in pistons with a hard-wearing surface. Alloys of aluminium with magnesium, one of the oldest classes, received a new lease of life through growing knowledge on the technique of casting magnesium and its alloys, and the 10% magnesium alloy, homogeneised, came to the fore for certain special castings called upon to stand heavy stresses (Fig. 1). These alloys are too well-known, and have been too frequently reviewed in detail elsewhere, to need more than a passing reference as milestones in light casting alloy progress. But it is a fact that many progressive ideas in metallurgy and control and production methods in this country lay fallow during the years under review. Foundries remained mainly jobbing foundries, continually improved in detail, but laid out essentially with an eye to flexibility in the handling of a wide variety of patterns, from which relatively few castings would be needed per contract.

The Factor of War

Why should the mere fact of war alter this picture? Simply because the need is then for enormous output from relatively few patterns, the exact reverse of con-

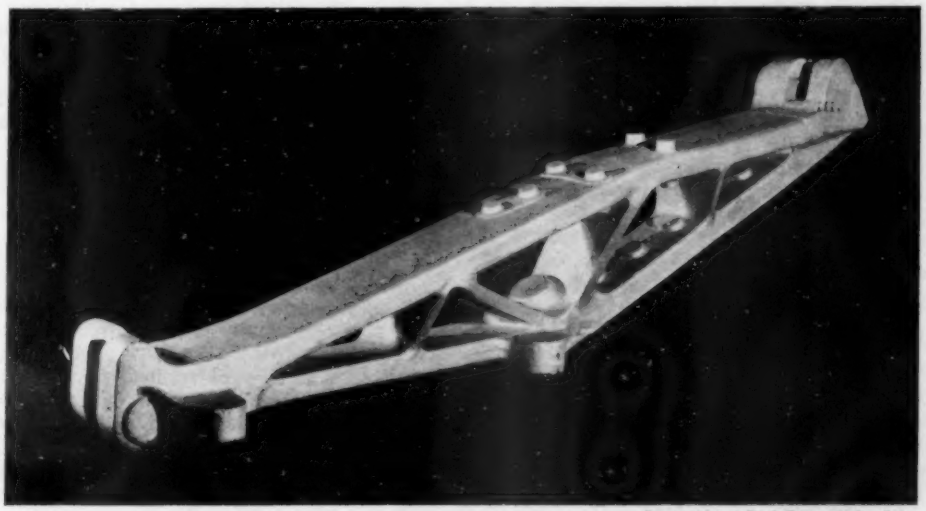


Fig. 1.— Undercarriage beam of a Lancaster bomber. Diecast in 10% magnesium alloy. Weight 124 lbs.

By courtesy of Firth-Brown & Co. Ltd.

By courtesy of Rolls Royce, Ltd.

Fig. 2.—Modern core-shop lay-out. Steel sand conveyers remove cores to core stove form the end of each bench. Sand distribution shutes deliver core sand directly on core-makers' benches.

ditions normal to this country. Further, that output must not be jeopardised by a high percentage of rejects, in the face of the fact that it must be obtained through the extensive use of a type of labour strange to the atmosphere and art of founding metal.

The laying out of a foundry for vast outputs of sand- or die-castings, is a matter of experience and applied common sense, and a war gives our experts the chance they have waited for and are mentally equipped to meet. The Rolls Royce sand and die-casting foundries offer one good example of the resulting release from the "jobbing" complex (Fig. 2), but there are many others to choose from. There is, for example, one light alloy foundry in the Midlands distinguished for a complete absence of molten metal in the moulding bays, a unique factor which makes for the comfort and health of the moulders. Under the stimulus of this war the United Kingdom, which always commanded a wealth of technical ability, now possesses some of the finest aluminium alloy foundries in the world.

It is, however, one thing to plan and bring into operation a modern mechanised foundry, and quite another to ensure consistently high quality production of masses of castings day after day, by relatively unskilled labour. The standard of quality called for by aircraft is high, and if it cannot be obtained consistently much of the value of high output capacity is necessarily lost, both in the foundry and in subsequent machining hours. This is where science steps in, with meticulous control of the metals used and their alloying and melting; with central control of sand texture and moisture content; with metal patterns, jigs and gauges of tool-room accuracy, and with every possible device to reduce the human factor and the normal variables of a foundry to a bare minimum. And finally, most important of modern aids to perfection, science has given us the means of seeing for ourselves, by means of the X-Ray, the internal structure of our work, so that we do know what is being delivered without, as heretofore, waiting for the customer's machining report. The laboratory, planning department, tool room, pattern shop, go into committee, so arranging details of production that a boy or a girl or a labourer from the fields can, merely by following a set sequence of operations, turn out castings at least as good as the skilled worker of the past, and produce vastly greater tonnages per man-hour. The skilled craftsman is not jettisoned, but becomes supervisory; there are never enough of him to form the necessary leaven of skill in the gangs of the willing but unskilled.

The casting of industrial parts can be done in sand, in more "permanent" moulds of metal or other materials, and in steel dies under pressure. If we take these in this order we can review items of progress noted as far as the United Kingdom is concerned.

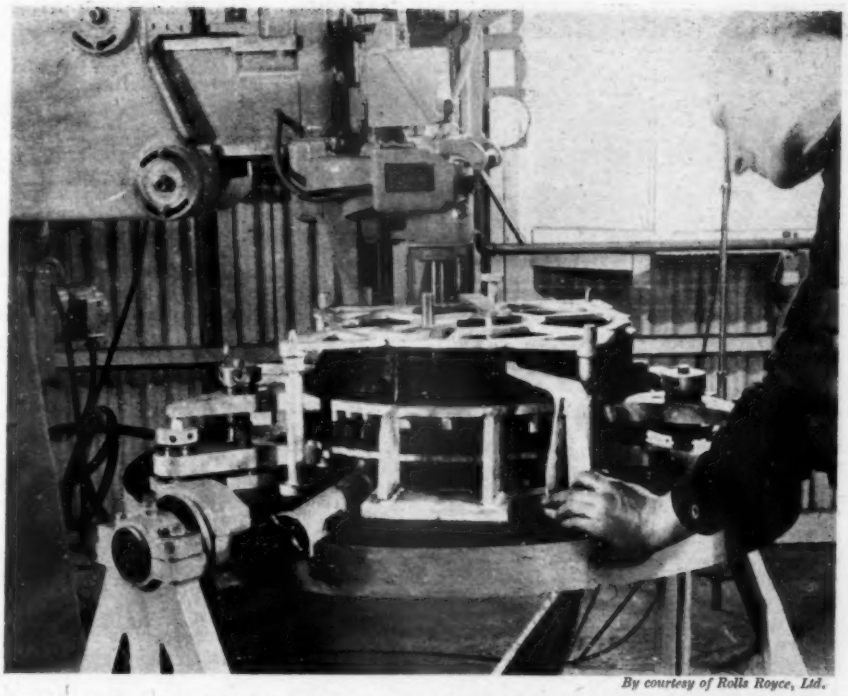
Sand Moulds

Clearly the kernel of the matter here is the quality of the sand as manipulated by the moulder, its grist grading, clay and moisture content, permeability, and above all, the day to day consistency of these properties. The incidence of sand preparation on quality of the subsequent casting is so generally recognised that it has been the practice, in the dim past, for moulders with a reputation to sustain to mix their own sand, and become as it were a sort of allotment worker when they should have been concentrating their skill on moulding itself.

For many years American founders have done yeoman service on practical research into foundry sands, fixing specifications for grists, permeability and moisture content, with simple foundry tests for same. We in this country also did much useful work behind the scenes, but with this difference in most cases. Whereas the U.S.A. were blessed with a huge internal market, which justified the heavy capital outlay on central sand treatment and the related collection and distribution plant, it was not until the current war that we found ourselves in a similar position. Prior to the war it was more common to encounter localised, floor mixing and tempering of sands; now it is on the whole more common to see the centralised sand treatment plant, with all that implies in economy, in the substitution of scientific control for the human factor, and above all, in sheer consistency in texture and temper of the sand as it reaches the moulder. In other words, one of the long series of variables which can scrap an expensive casting ceases to be a variable. There were always many specialised foundries in this country using this system as a matter of course; the present advance lies in the

extension of this form of insurance against variation in the stock mould and core materials, with consequent variation in quality of the product cast in those moulds. The composition and temper of the sand as delivered by the central treatment plant is set by the laboratory, and the consistency is constantly checked on a scientific basis.

The next most notable advance observed lies in the (to the author) amazing accuracy of pattern work and the jigs and gauges supplied for setting of cores, etc., and for checking final dimensions and form. (Fig. 3). The quantities of castings now produced permit of metal patterns and core-boxes, machined to the precision of dies, and usually the whole gating system is made integral with the pattern. This precision applies throughout to all the numerous jigs and gauges used from start to finish, an insurance in its turn against rejection of castings which are metallurgically sound but not dimensionally correct. The importance of this factor is realised when it is stated that Merlin castings, for example, must be produced to a normal permissible wall-thickness tolerance of plus or minus 0·025 in.



By courtesy of Rolls Royce, Ltd.

Fig. 3.—A close-up of the final dimensional check known as " Jig and Spot " location. By this method each casting is accuratelychecked and proved, and receives three machined datum faces and dowel locations from which the machine shop can set up. This entirely eliminates " marking out " of castings in the machine shop.

An obvious increase in the use of moulding machines is noted, for obvious reasons, but there seems little change in design except in details making for accuracy, ease of operation, and low maintenance charges. Machines of the Sandslinger type are more in evidence for intricate work than was seen formerly. The Sandslinger came in as the ideal for products such as cast iron baths or the Alpax doors of the Underground Railway, the first requiring the rapid supply of a large volume of sand, which a jolt ram would pack hard at the bottom and progressively lightly towards the top, and the second taking so small a depth of sand that little ramming could occur with a jolter. The Sandslinger did both jobs efficiently and easily, and many others of a similar type. Recently this type of moulding machine has been used with success on large aero engine crank-case castings, especially where chills have to be used of such weight, or so positioned, that a jolter might displace them. If the slinger has a disadvantage it is that it requires a separate machine for turning over and withdrawing the pattern, so that the tendency to this wider adoption is the more interesting to watch.

Cores have always lent themselves to rapid production by gangs of relatively unskilled labour, but here again the human factor militated against that even, consistent packing which makes for consistent castings. It is, therefore, interesting to observe the extended use of core-blowing, in which compressed air is used either to push the sand into the core-box, or to introduce it in a jet of mixed air and sand. Ramming is more consistent and controllable by the management, and cores start with a high degree of the porosity desirable with light alloy work. The human factor came in also in the baking of cores in small ovens located near the core benches, now widely supplanted by central automatic ovens, through which the cores pass on conveyers, under drying and baking conditions which can be set by the management and automatically adhered to. There is a wide use also of core carriers which are replicas of the core-box, and in which the cores rest throughout their journey from the bench, through the ovens to the point at which they are used. These carriers practically eliminate distortion of intricate cores during baking. Their use is a good example of the principle that prevention is better than cure, which now permeates the aluminium alloy foundry from start to finish.

The dirty end of a foundry is still the section where the castings are freed of sand, but much improvement has been effected by breaking out moulds over gratings on to underground conveyers. Through those gratings air is drawn continually in considerable volume, taking the clouds of hot sand dust with it. The removal of cores seems to demand a lot of hand scratching and winkling out, despite ingenious use of pneumatic hammers (Fig, 4) with simple fixtures. Hammering by hand or mechanical means can be hard on hot (and therefore still delicate) light alloy castings, and it is therefore interesting to learn of the use of the " Hydroblast " in light alloy work. Should this prove the answer it will set one more nail in the coffin of this tiresome operation and

By courtesy of Rolls Royce Ltd.

Fig. 4.—Pneumatic fixture for core removal.

its normal accompanying atmosphere of fine dust.

Advances in the dressing of castings are mostly detail improvements in lay-out of the generally accepted bandsaw plus pneumatic chisel plus grinding wheel equipment, but one very useful tool must be referred to This is a massive duplex circular saw (Fig. 5), a robust and accurate machine tool, which will remove smoothly and expeditiously the bulk of the gate and riser assembly from a large crank-case in a few minutes. The accuracy of this tool cuts out the necessity for allowing extra metal for the vagaries of bandsaw operations.

Die-Casting

In this process metal moulds are used instead of sand, and the moulds are filled either by gravity or pressure. The two broad groups are known as gravity and pressure die-casting, though there is a recent tendency for the two clearly defined classes to merge.

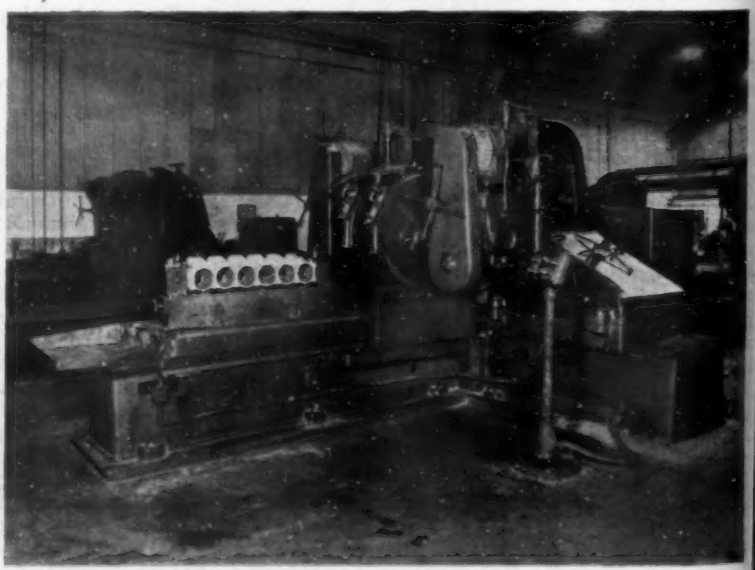
Gravity die-casting usually takes place in cast iron moulds, and is applicable to a wide range of engineering parts. Outlay on dies is relatively low, and the product is distinguished by a fine metallurgical structure not normally obtained in sand castings. The process has been described at frequent intervals in considerable detail, and reference here will be confined to two recent improvements which have extended the field of use and raised the standard of the product.

The first is in connection with the production of very thin fins, such as are found on air-cooled cylinders of aircraft engines. Always a difficult class of work, the difficulties in the case of such cylinders were increased by the fact that the alloy best suited to the production of thin fins was not necessarily the best for cylinder service conditions. A change came with the introduction of casting, either in partial vacuo, or by withdrawing air from the mould as the molten metal entered. This meant that the passage of the molten metal, right up to the limits of the slim mould boundaries, was not hindered by a cushion of air which must be displaced by the rapidly cooling metal itself. The result has been not only a surprising improvement in the definition of fins, but also an opening of the path to the casting of even thinner and deeper ones, thus enabling designers to improve engine performance. Fig. 6 will suffice to indicate how this principle may be applied to widen the field of gravity die-castings in directions formerly closed to the process.

Pressure Feeding

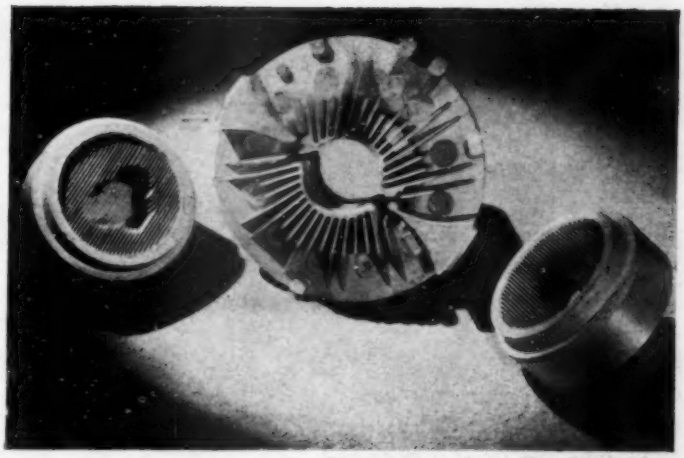
The second advance is of personal interest to the author, who read a Paper on Die-Casting to the Inst. of Metals in 1926. In his summary of the possibilities and limitations of the die-casting process at that date he said, "We await the advent of a machine which pours by gravity and applies great pressure immediately afterwards." It is one thing lightly to throw out such a suggestion, and quite another thing to have the courage and enterprise to develop the idea, and it is to the credit of a famous light alloy foundry of the Midlands that the principle has attained a high degree of development. As anticipated, the principle of tranquil filling of the mould, followed by feeding under considerable pressure, has resulted in a metallurgical structure and soundness practically in a class of its own, a class in which physical

Fig. 5.—Wadkin duplex saw for removing gate and riser assembly. Background, horizontal model of same machine.



properties and solidity are comparable with those found in forgings, whilst the freedom of design of a casting is retained.

Pressure die-casting proper usually takes place in steel moulds machined to fine limits, and in some pressure die-casting plants the tool room represents nearly 75% of the outfit. Castings are distinguished by fine definition and finish and dimensional accuracy, and can be produced in large numbers at high speed, but until recently the product has not been noted for metallurgical soundness. In the past the usual method was to inject metal into the mould under high pressure, filling a mould in a split second. Where the metal met mould walls it froze, and there was little to feed the space between in the time allowed, so that the core of the casting was porous and spongy. Whilst pressure die-castings were in enormous demand for industrial parts calling for large quantities of accurate, cleanly defined castings at low cost, they were seldom used for engineering parts needed to withstand much stress.



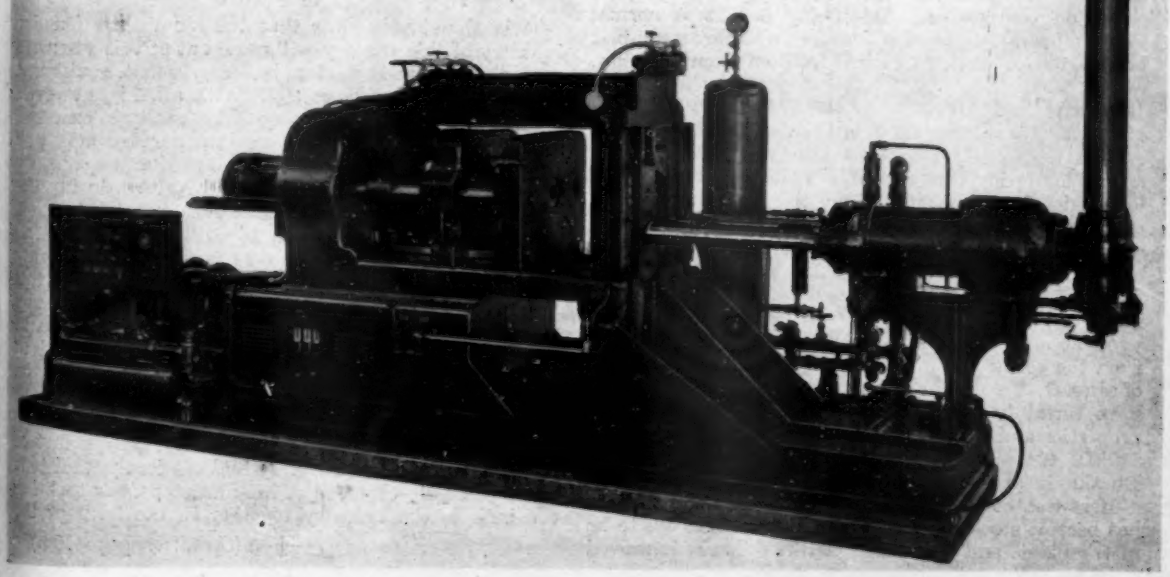
By courtesy of Aeroplane & Motor Castings Ltd.

Fig. 6.—Air-cooled cylinder-head castings produced by the "part-vacuum" process. Cooling fins for the small castings only 0.030 in. at the tip, with 1° draw on each side face.

A change came over this picture also with the introduction of the "cold chamber" machine and its modern variations. Instead of metal being literally shot into moulds by the sudden application of pressure to the molten surface, a small measured amount is ladled into a space in front of a pneumatic or hydraulic ram. The ram is caused to advance or to rise, forcing the metal steadily into the mould under increasing pressure. The resulting castings have all the accuracy, definition and minimum scantlings of the former pressure casting, whilst sharing in useful measure the physical properties of the gravity poured job. Several versions of die-casting machines of this class are now marketed, and are worthy of study as a distinct technical advance on the old "goose-neck" machine (Fig. 7).

In thus lightly touching upon these high spots of process improvement seen during the war, it is easy to overlook the main body of improvement not so readily illustrated by concrete examples. There is to-day a notable absence of that trial and error, that almost haphazard approach to a casting problem which could be seen in the past and which was by no means confined to this country. The author recollects asking a founder in the States how he arrived at a peculiarly neat gating and riser assembly seen on a certain job. Was it worked out from first principles, or did he just toss up for it? His reply, in a flash, was that they did not toss up for it, but they did "cast lots" before arriving at it. Nowadays, a casting proposition goes before a sort of Brains Trust, often including the designer of the casting, and the correct lines on which to start are laid down in detail. It is then cast

Fig. 7.—Modern die-casting machine of the "Pre-fill" type.



By courtesy of The British Aluminium Co., Ltd.

Fig. 8.—The modern spectrographic control of melts dispenses with the test tube in favour of the slide rule.

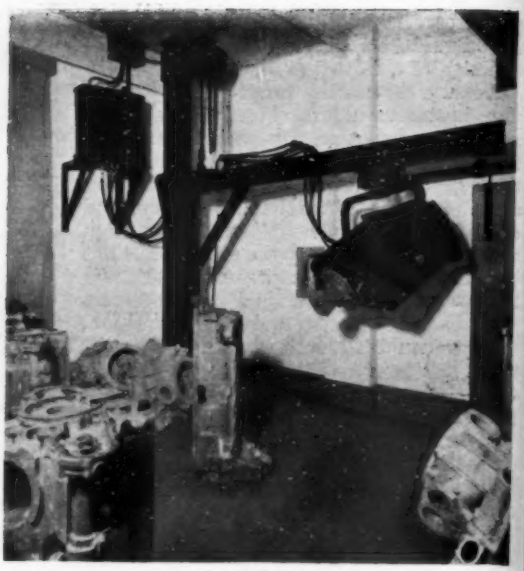


Fig. 9.—X-ray equipment has evolved into a compact and practical foundry tool.

in an experimental bay, and the casting subjected to meticulous examination by X-Ray; to porosity and dimensional tests; and finally to slicing up for physical tests. Only when the job is perfect is it allowed to go into the production bays, and then as much as possible of the gating system found to give the best results is made integral with the patterns. All foundry variables, and heaven knows they are legion, come under scrutiny and are eliminated as far as practicable, even down to fixing the height from which metal is poured into moulds by simple fixtures on the flasks.

The modern tools of spectrographic (Fig. 8), polarigraph and colorimeter methods of analysis are in routine use, not only to check raw materials, but to supplement chemical methods in a general speeding up of analyses. This speeding up makes possible the economy of continuous bulk melting, with constant check on composition. De-gassing is now a normal foundry operation, but few founders who throw a tablet or two into a melt, to ensure freedom from pinholes, realise what they owe to the work of such men as Rosenhain and Archbutt, of the N.P.L., and Hanson and Slater, of the British Non-Ferrous Metals Research Association. The latter Association also has been responsible during the war for much clarification of knowledge on points such as hot-tearing characteristics of the many casting alloys, their relative solidification shrinkage, their fluidity and many similar factors which come into the picture of general "castability." Apart from the high-strength, heat-treated class of alloy, the industry has had to learn how to use up the masses of wrought alloy scrap of the Duralumin type, accruing from the construction and destruction of vast numbers of aircraft. Two of the alloys developed for this purpose have certainly come to stay, both for good foundry properties and for a sound record of service. They are D.T.D. 424 and L.A.C. 10, both of which use scrap Duralumin as the main ingredient.

Heat-treatment of castings of all designs and weights has become stock practice where high stresses are to be met. Plant and handling facilities have improved greatly, and there is a far wider knowledge of the metallurgical changes involved. Tests for porosity have been improved, one of the most searching being the simple chalk test used by the Rolls Royce foundries, in which castings are first immersed in hot oil for a period, then thoroughly cleaned off, and finally dusted with French chalk. Porous patches tend to show up strongly in the subsequent inspection, by reason of the slow seepage of traces of oil absorbed by such patches. Above all the former clumsy and intricate X-ray equipment has evolved into a compact, robust and very practical foundry tool (Fig. 9), and has much simplified life for the founder who wanted to know something of the inside of his work before it reached his customers'

The Future

It is abundantly clear that the aluminium foundry industry of this country will come out of this war with a goodly heritage in modern buildings, plant, equipment and highly trained personnel. With all this, however, comes the less desirable legacy of a capacity in excess of the probable demand. The post-war demand may well be double that of the pre-war. The production capacity of the country has been multiplied by five during the war. Reversion to normal shift working may bring that down to around 3·3, which is still a problem in an industry which, even in pre-war years, was too highly competitive to be lucrative. Like many others, this vital industry will face post-war problems which, whilst by no means insuperable, may call for a new angle of approach.

When the late Mr. Percy Pritchard was asked to undertake the thankless task of bringing into being the Light Metals Castings Control, he was surely faced with problems as intricate as could be found in connection with any control. Actually this was one of the first of its class to function smoothly and efficiently, and it is worthy of note that one of his first steps was to bring the bulk of the industry together in the form of the

(*Contd. on page* 196.)

Aluminium Alloy Sheet and Strip

By E. G. West, Ph.D., B.Sc.

The early use of aluminium alloy sheet was devoted almost wholly to kitchen utensils for which certain alloys were found to be particularly suited, but increased metallurgical knowledge, together with improved forming technique, gradually increased the fields of usefulness for this metal, and it is doubtful whether greater progress has been made than in the production and use of sheet and strip. Here the author surveys these products of the aluminium industry and directs special attention to the remarkable progress so far achieved.

IT is fitting that the development and present position of aluminium alloy sheet and strip should be considered at the present time, when Industry stands at the threshold of a new era of light alloy utilisation. From an industrial curiosity of some 50 or 60 years ago, aluminium and its alloys now occupy a key position in national—indeed international—economy, and of the various forms in which light alloys are used, sheet and strip, plate and foil, account for a major proportion.

Looking back to the work and progress already accomplished, clear indications may be seen of the expectations for the future. As the aluminium industry as a whole has increased in capacity and industrial stature during the war years and intends to build its peacetime applications on the basis of its accumulated experience, so the rolled sheet producers and users will draw upon the knowledge gained within the last few years.

One of the earliest recorded applications of rolled aluminium in this country was in 1898, when aluminium plates were produced by the Scottish Aluminium Co., Ltd., whose rolling mill at Greenock was supplied with aluminium by the then young British Aluminium Co., Ltd. Motive power was supplied by turbines fed by water from the Greenock Water Trust, and the successor to this firm was the Combined Metals Co., Ltd., which produced rolled bimetallic sheets. It is interesting to note that the aluminium sheets incorporated in one of Sir Thomas Lipton's famous yachts were rolled at this mill—a very early marine application.

The production of aluminium sheet was undertaken, by the British Aluminium Co., Ltd., at an early date and during the 1914-1918 war the development of aluminium alloys was undertaken on a large scale. Rollers of other non-ferrous metals entered the field and during the period from the end of the last war and the commencement of the rearmament programme the foundations of the present wrought aluminium alloy industry were made.

Between the wars the industry was concerned mainly with supplying relatively small quantities of rather specialised sheet and strip to several industries, in particular, aircraft constructors, public service vehicle suppliers and makers of domestic utensils and equipment. When it became apparent that large scale production was required, more modern plant was installed and efforts were made to reduce the number and variety of the alloys and the sizes and gauges of metal in process. This was of assistance in increasing production and simplifying rolling procedure.

The high performance of British all-metal aircraft has contributed to the high reputation of aluminium alloy sheet and strip, and to-day's high technical position has been gained by intensive research and development on the part of the producers and users of the metal, together with the makers of rolling mill plant. Good material can be produced only by proper attention to the metal from its reception into the works to its despatch and ultimate manipulation, so that it is necessary to consider the principal rolling treatment of aluminium alloys.

Rolling mill practice for aluminium alloys had been dealt with in the literature,[1] and it is not proposed to include the fundamentals in the present review. Equipment is similar, in principle, to plant required for other non-ferrous metals, and in the early days it was often adapted from plant installed originally for copper alloys. The scale and magnitude of plants in operation in this country are not of the same order as some of the U.S.A. plants, but they are, in general, more versatile and capable of ready adaptation to many peacetime requirements. The size of plant is still increasing, and certain installations are tending towards steel sheet and strip practice. A number of descriptions of typical plant[2] here and abroad have appeared, and the similarity to steel rolling practice is well shown by such articles as the recent one by Ess.[3]

Melting and Ingot Production

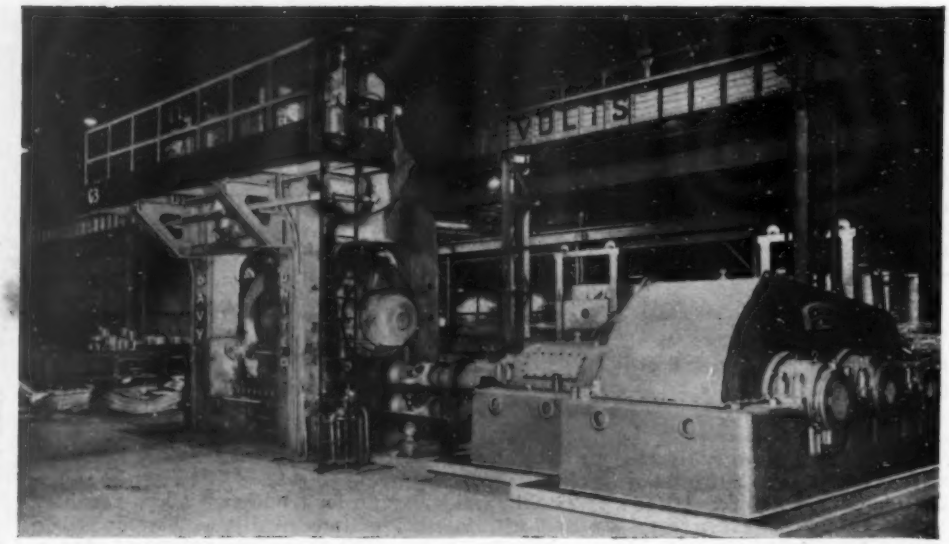
Aluminium alloys are cast either into ingots or slabs for hot rolling direct from the as-cast condition or into billets which are first extruded to give slabs for subsequent hot rolling. In each case, particular attention must be paid to the production of non-porous and fine grain metal, and somewhat revolutionary ideas have been developed to assist in obtaining the desirable characteristics in the cast material. The use of extruded rolling slab permits more latitude in hot rolling practice, and reduces edge cracking during hot-rolling, but the extrusion process imposes a serious limitation on the size of the slab, and thus on the finished plate or sheet. Hence, for the production of large sheets or thick plates, the use of cast rolling slabs is necessary, and a great deal has been learned about the technique required for producing rolling slabs of the desired properties in the large sizes demanded by marine requirements.

Melting for the production of rolling or extrusion slabs is now normally carried out in coke-fired reverberatory furnaces which allow melting costs to be kept to a minimum. It has been found possible to use a considerable proportion of scrap, and this is largely as a result of the efforts made to secure efficient segregation

1 C. E. Davies and L. R. Underwood, *Met. Ind.*, 1944, LXIV, pp. 306–309, 322–324 and 338–340. O. Emicke and K. H. Lucas, *Z. Metallkunde*, 1942, **34** (2), pp. 25–38, (3), pp. 49–55. Sachs and Van Horn, "Practical Metallurgy."

2 *Mecanique*, July, 1943, No. 315, pp. 217–220. H. Selaczek, H. Zapp and B. Stockbauer, *Met. Ind.*, 1939, LIV, pp. 459–462. James, *Engineer*, June 2, 1944, pp. 420–422.

3 T. J. Ess, *Met. Ind.*, 1944, LXIV, pp. 194–195.



By courtesy of Davy & United Engineering Co. Ltd.

A 16 in. × 42 × 68 in. 4-high cold sheet finishing mill for duralumin type alloys.

of both fabricators' and users' scrap of all kinds, during the war period. Melts exceeding 70% scrap content are made satisfactorily in many of the commonly used alloys, thus leading to valuable savings without detriment to the quality of the finished product.

De-gassing is normally carried out by passing chlorine through the metal in the ladle. A central chlorine store with piped supplies to the proper places in the foundry is usual, with, of course, suitable ventilating arrangements.

A particularly satisfactory method has been developed to ensure the production of the necessary fine grain and absence of segregation in the slab, namely, the continuous casting process. In this process the metal is poured into a shallow mould, the base of which is lowered while the mould itself is cooled by water sprays. Both rolling slabs and extrusion billets are cast by this process.

Preparation for Hot Rolling

Blanks or slabs prior to hot rolling are usually scalped completely, and a number of types of milling and scalping machines are in use, including the necessary mechanism for handling the weights involved. In some cases pickling in a hot caustic soda (10–20%) solution, followed by a dip in nitric acid, is employed instead of scalping, or scratch brushing may be carried out. Slabs from extrusion are either pickled or scratch brushed, particularly when aluminium-clad high-strength alloy is to be made.

For the production of aluminium-coated sheet and strip, such as DTD.390, a sheet of high purity aluminium is placed on each side of the prepared slab and wired in place before the metal is placed in the pre-heating furnace. The wires are, of course, removed when the metal is removed from the furnace immediately before hot rolling commences.

Rolling slabs are pre-heated, usually, in gas-fired furnaces, the metal being conveyed through the furnace by some suitable mechanism such as a pusher conveyor. The soaking time required prior to hot rolling depends on the type of alloy, and, of course, the thickness of the billets, but it is essential that adequate time is allowed for this most important operation. In cases of doubt, it is advisable to prolong the time rather than shorten it, and some measure of control, automatic or otherwise, is desirable to ensure that each billet withdrawn from the furnace has received sufficient soaking.

The temperature is again determined by the type of alloy but it is not as critical as in the case of full heat-treatment. Temperatures for hot rolling are summarised in Table I.

TABLE I.

Alloy	Temperature of Metal for Hot Rolling	
	At Start	Lowest Permissible
Aluminium	480–520° C.	280° C.
Aluminium-magnesium (3–5% Mg.)	400–450° C.	360° C.
Aluminium-Mg_2Si type	460–500° C.	400° C.
Duralumin-type	400–440° C.	360° C.

Hot Rolling

Hot rolling is always the first operation in breaking down either as-cast or extruded slabs. The metal is, of course, conveyed on a live roller system and 2-high, 3-high and 4-high mills may be used. Non-reversing 2-high mills are arranged with lifting tables for conveying the metal back after each pass, but modern rolling mill practice now allows reversing mills to be used for this initial breaking down stage. More recently still, 4-high mills have been used for initial hot rolling, and it may be that this will become more general in due course. The number of passes required depends, of course, on the allowable pinch, which again is a function of the composition of the alloy. This varies from reductions of 20 to 30% in the case of pure aluminium to only a few % reduction per pass in the case of alloys which might otherwise crack. Hot rolling speeds run from 100 to 200 ft./min. and roll temperatures are kept down by the use of a suitable cooling liquid liberally applied. A mixture of soluble oil and water is usual, but in addition the rolls are also lubricated with a suitable oil mixture in order to minimise friction.

After hot rolling the thick sheet or plate is trimmed to remove cracked edges and may then be reheated for further hot rolling or transferred to annealing and cold rolling.

Cold Rolling

Cold rolling is generally referred to in two stages, the first being usually known as "getting ready," while the second is the final or finishing stage. In order to obtain maximum uniformity of properties in the metal, the direction of rolling is changed as frequently as possible, usually after annealing in the "getting ready" stage. Cold rolling of plate is carried out at 100 to 250 ft./min. and again the amount of reduction possible between annealing varies from as much as 90% in the case of pure aluminium to less than 50% in the case of certain alloys, although 50 to 75% may be taken as an average.

Strip is rolled in a series of mills and is coiled on a drum-type coiler, the speed of which is synchronised with the rolls by a suitable system (e.g., Ward-Leonard) in order to ensure a steady tension between the rolls and the coiler. Strip rolling speeds in 2-high and 4-high mills range from 150 to 400 ft./min. and the speed finally controls the thickness of the metal.

Following the production of strip, it may be required to continue rolling to produce foil, particularly pure aluminium foil, for which special mills have been developed, including cluster mills of 6, or even 12 rolls. Speeds may range from 400 to 1,200 ft./min., but the maximum economic speed is generally below the actual maximum, owing to the time required for handling. Foil as thin as 0·0002 in. is produced and final thickness is again determined largely by the speed and by the tension applied by the coiling drum to the strip.

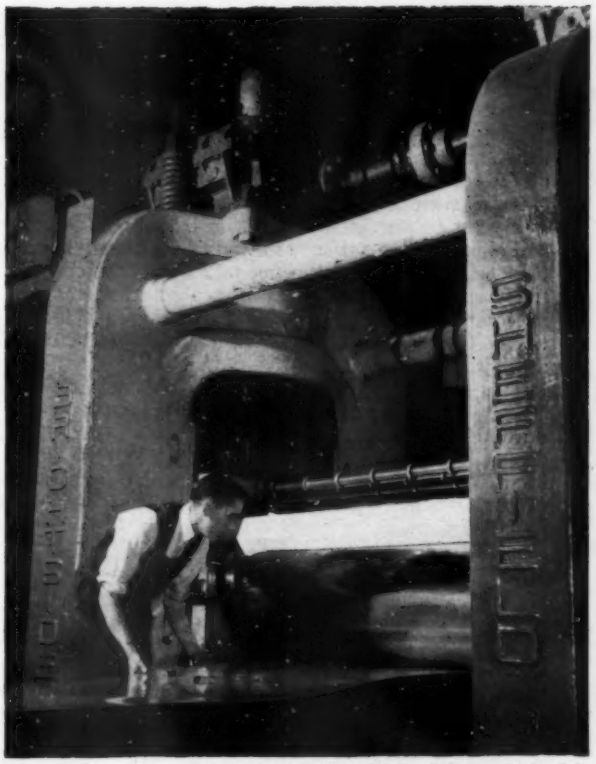
Annealing and Heat Treatment

Intermediate annealing is necessary in the production of cold rolled sheet and strip, and in the case of the heat-treatable alloys, the heating period must be followed by slow cooling in order to avoid age hardening. The temperatures for annealing the various classes of alloy are summarised in Table II. Furnaces used may be heated electrically or by town's gas or producer gas, and to-day automatic temperature control is invariably employed, furnaces usually being sub-divided into several zones each with independent instruments.

TABLE II.
ANNEALING TEMPERATURES FOR ALUMINIUM ALLOYS.

Alloy Type	Temperature Range	Remarks
Pure aluminium	320–360° C.	Heat rapidly to temperature and cool at any convenient rate.
Aluminium-manganese (1¼% Mn.)	350–390° C.	
Aluminium-magnesium (2–4% Mg.)	340–380° C.	
Aluminium-magnesium (7% Mg.)	370–420° C.	
Aluminium-Mg_2Si	330–360° C.	Slow cooling.
Duralumin types	(i) 330–350° C. or (ii) 400–425° C.	Slow cooling; or Cool at 15° C. per hour to 320° C.

The heat-treatment of aluminium alloy sheet and strip is carried out either in salt baths or forced air circulation furnaces. Salt baths may be heated by gas or electrically, modern equipment making use of immersion heaters which result in not only greater thermal efficiency but also improve the temperature distribution in the bath. Coiled aluminium alloy strip is often heat-treated in an air furnace, which again may be heated electrically or by gas, but in the latter case the products of combustion should not be allowed to enter the furnace chamber, particularly in the case of producer gas. Work by Stroup[4] shows that the water vapour present in the products of combustion, especially in the presence of traces of sulphur gas, may result in the development of blisters, so that a separate combustion chamber is necessary, except where radiant tube heaters are used. Forced air circulation is essential in order to transfer heat quickly from the heating elements or tubes, and air velocities as high as 5,000 ft./min. are used in some installations. Continuous furnaces are not used for solution heat treatment, and batch type furnaces may be either arranged vertically or horizontally with adequate handling arrangements in each case to allow rapid removal of the metal from the heating chamber to the quenching tank.



By courtesy of Brightside Foundry & Engineering Co., Ltd.

Finishing aluminium alloy sheet.

Before coiled strip can be heat-treated it is necessary to loosen the coils to allow proper circulation of the heating medium and quenching water. This is done by unwinding the coil and corrugating or dimpling the edges followed by rewinding on to a collapsible drum. After heat-treatment the coil is passed through a levelling machine and the edges trimmed off.

Sheet also requires levelling, and this is carried out on the usual form of roller leveller. Both sheet and strip may be run through a high speed mill after solution treatment to give a very small reduction to finished gauge.

The normal age hardening alloys then attain their maximum properties at the end of 4 or 5 days, but precipitation hardening alloys require, of course, re-heating at temperatures between about 150 to 190° C. The time required to produce full ageing may be as long as 20 hours, depending upon the temperature employed, and for this work it is usual to used forced air circulation furnaces, again heated either electrically

4 P. T. Stroup, "Atmospheric Control in the Heat Treatment of Aluminium Products," A. S. M. Symposium, *Controlled Atmospheres*, 1942, pp. 207–220.

or by gas, providing the products of combustion are not in contact with the work. There is no distortion after precipitation heat-treatment.

Formed Strip

Long lengths of strip, usually not more than $\frac{1}{8}$ in. thick, are formed to shape by drawing through a series of dies or specially shaped rolls, and tremendous quantities of such formed strip have been used during the war years in aircraft construction both in this country and abroad. The strip as received from the mill is cut to the desired width, care being taken that the edges are free from burrs. The metal is then solution treated, if necessary, passed through a flattening machine and thence to the draw bench. Lengths of formed strip are also produced on press brakes and folding machines, but these are limited to a maximum of some 12 to 20 ft. long. Sections may be straightened by slight stretching, particularly when they are solution treated after drawing. Strip formed in this way is likely to play an increasingly important part in peacetime applications of aluminium alloys, particularly in view of the wide range of forming properties covered by the alloys as a whole.

The Future

It is to be expected that the aluminium industry will take advantage of all the advances which will undoubtedly be made by the designers and manufacturers of rolling mill equipment of all kinds, and there will be undoubted engineering developments in this field which will facilitate the production of aluminium alloy sheet and strip in larger quantities at lower costs, and of still higher quality. In addition to major developments, improvements in detail, such as lubrication and handling technique, may also be expected.

As the field of applications of aluminium alloys extends, demands are arising, and will continue, for larger plates, and for longer and wider coils of strip. The more extended use of aluminium alloys for marine purposes, particularly for super-structures, as outlined for example by Muckle,[5] will require the production of large plates up to perhaps 1 in. in thickness, in the appropriate alloys to withstand marine corrosion.

A certain amount of research has already taken place on the development of "deep drawing quality" high strength sheet,[6] and further work on these lines may be expected to have an effect on methods of production to give the required characteristics, in a like manner, the demand for improved weldability, especially of high strength sheet and strip, may well result in changes in alloy composition and methods of production of sheet and strip to give improved weldability.

New sheet materials may also be expected; for example, sheet of the type of alloy covered at present in this country by D.T.D.363A (Cu. 1·5–3·0% Mn. 1·0% max.; Mg. 2·0–4·0%, Si. 0·6% max., Fe. 0·6% max., Ti. 0·3%, Ni. 1·0% max., Zn. 4·0–6·0%). Clad sheet of this type has been produced with a coating of aluminium-magnesium alloy instead of pure aluminium, in order that the coating may be anodic to the core material, and hence preferentially attacked under corrosion conditions. Parallel with this it may be expected that the range of alloys may be somewhat simplified in order to facilitate their adoption by engineers in all branches of industry.

Another development which shows considerable promise is the combination of aluminium with other materials such as cellular plastics, expanded rubber, cork and plywood. Here the permanence and strength of aluminium alloys can be well combined with fillers of this kind to give sandwich materials of high strength and rigidity, plus a pleasing appearance and easy handling characteristics. Perforated or expanded sheet may also be employed as a core material to strengthen moulded plastics and laminated plastic sheet products, the low weight of aluminium alloys being particularly advantageous here.

Finally must be mentioned the likely use of aluminium alloys in the form of expanded metal, which after anodising and probably dyeing, may well prove of particular value in post-war architecture.

With the increased capacity of the industry and the expectation of reduced costs combined with a forward-looking development policy, the Aluminium Alloy Sheet and Strip Industry can confidentially expect increased activity in the post-war years.

5 W. Muckle, M.Sc., "Some Considerations in the Application of Light Alloys to Ship Construction, N. E. Coast Inst. of Engr. and Shipbldrs., *Inst. Trans.*, **60**, December 20, 1943.

6 J. C. Arrowsmith, K. J. B. Wolfe and G. Murray, "The Cold-pressing Properties of Duralumin Type Alloy Sheets, with special reference to the Production of Large Pressings for Aircraft," *J. Inst. Met.*, 1942, **68**, 109–132.

The Wartime Aluminium Foundry

(*Continued from page* 192.)

Light Metal Founders' Association. That Association has done a great work during the war in the sensible distribution of production, and in co-operative technical assistance, an asset to the nation in war which should not be allowed to lapse in peace. If again one analyses root causes of the very concrete contribution of that Association to the war effort, one quite unusual factor stands out. For once a Trade Association has been sponsored by that Trade's chief buyer. The buyer, via the appropriate Control, took an intimate interest in the deliberations and actions of the Trade, via the appropriate Association. That is an abnormal arrangement, since Associations are anathema to most healthy buyers, but it worked because quite abnormal problems of supply had to be faced.

Equally abnormal problems will accrue during the first few years of peace, and it may well be that they can be met for a period through some similar co-operative effort on the part of all interested in a steady and economical supply of light alloy castings, through an agreed distribution of types of work amongst those best equipped to produce the several types most efficiently. That implies the co-operation of some of the important buyers, in place of instinctive antagonism to all trade associations. If that thought seems revolutionary, it must be pointed out that in few walks of life will things ever be quite the same after this war, and that the millenium is scheduled to start with the lion lying down with the lamb.

NOTE.—Commencing with March 1st, 1945, the Minister of Aircraft Production will sell virgin aluminium in ingots and notch-bar form at £85 per ton, delivered into consumers' works, with extras for purities. This is a reduction of £25 per ton from the price which has been operative since the early months of the war.

Progress in Aluminium Die-Casting

By Arthur Street, Ph.D.

Although the past twenty years has shown remarkable progress in all the main sections for which aluminium or its alloys is applied, that associated with die-casting takes a prominent place. Aluminium alloy die-castings combine the accuracy, uniformity, and superior surface finish of die-castings in general with the lightness, strength, and high degree of resistance to corrosion of the aluminium alloys. This review indicates the high standard of modern production technique and provides useful guidance to industries seeking effective methods of production of non-ferrous components.

UNTIL a few years ago, any contributions to the technical press on the subject of die-casting would inevitably begin with a review of the scope of the process and a description of the methods by which die-castings are produced. To-day, however, die-casting is so well known that such an introduction would be redundant. The large needs of the Services led to a widespread use of die-castings in fuses, instruments of all kinds, aircraft components, radio devices, binoculars, small arms, components of motor vehicles, electrical fittings and many other uses. Furthermore, any manufacturer who has an inclination to think in terms of " post war " usually finds die castings entering into his ideas concerning the most effective methods of production of non-ferrous components, which are to be required in large quantities. The illustrations show some typical gravity and pressure die-castings in aluminium alloys.

Most technical journals, including of course METALLURGIA, publish frequent articles about aspects of die-casting ; indeed one excellent monthly American journal *Die-casting*, first published in November, 1943, deals exclusively with the design, production assembly and finishing of die-castings.

It is certain that this country has made an outstanding use of die-castings during the war ; for example our production is reported to have increased at a greater rate than that of America. Nevertheless, it is true that we are still behind in our contributions to man's knowledge of the theoretical factors involved. For example, America has done more than we have in the development of the die-casting alloys and the Germans have been most progressive of all nations in studying the problems connected with the injection of fluid metal into dies, starting with the work of Prof. Frommer[1] whose treatise on die-casting is still awaiting complete translation and publication in an English edition. The writer has hopes that one day we may see a die-casting research institute supported by the industry, coupled with some really up-to-date and useful work by one or more of our universities.

Particularly in the last few years the exponents of zinc alloy die-castings in Britain have been very active in publishing knowledge, views and suggestions concerning that branch of the industry, but less notice has been attracted concerning their achievements with aluminium base alloys. This is to be regretted, since light alloy die-castings possess many excellent qualities and they have reached a far greater advancement than is realised in some quarters. Furthermore, the probability of a considerable reduction in raw material cost

Fig. 1.—Aluminium alloy gravity die-casting, illustrating use of sand cores for undercut portion.

makes it likely that in the coming years aluminium alloy die-castings will compete effectively with the ubiquitious zinc alloys on a cost basis, quite apart from considerations of lightness, finish, and electrical and thermal conductivity.

It is noticeable that in this country two schools of thought exist concerning the relative merits of gravity and pressure die-castings in the aluminium alloys. This has become more pronounced since the major pressure die-casting firms (whether specialising in aluminium or zinc base alloys) have tended to act together during the war in technical discussions with Government departments while a separate approach has been made by gravity die-casters.

Many users " swear " by gravity die-castings while others favour those produced by the pressure process. The most controversial point has concerned the solidity or otherwise of aluminium pressure die-castings. It must be admitted that when produced on hot-chamber low-pressure machines, aluminium alloy die-castings suffer not only from porosity but from iron pick-up and from the effects of the somewhat higher casting temperatures needed in hot-chamber plants. Since the widespread use of cold-chamber machines, with pressure between

1 Leopold Frommer, " Handbuch der Spritzgusstechnik " (book) published by Julius Springer, Berlin (1933).

Fig. 2.—Part of aluminium alloy pressure die-casting, illustrating undercut.

2–4 tons per sq. in., a considerable advance has been made in aluminium die-casting production. Furthermore, since the alloy is melted in a separate crucible, absorption of iron, which previously caused undesirable mechanical properties and troubles in machining, can readily be prevented. The crucible used for melting the alloy is either of a refractory material or of cast iron coated with refractory, both procedures having the effect of preventing iron absorption.

The table below states some relative merits of the two types of die-castings as concerns the aluminium alloys.

TABLE I.

Suitable Quantity	Up to 5,000 for gravity die-casting. Over 5,000 for pressure die-casting.
Speed of production	Up to 50 per hour for gravity die-casting. Up to 200 per hour for pressure die-casting.
Use of Multiple Dies	Not very frequent with gravity dies, while in the pressure process the procedure is often adopted, thus making still greater production possible.
Solidity	As a general statement it can be said that gravity die-castings are less difficult to produce solid than pressure castings. This is partly because the gravity process admits the use of risers, venting cores and other devices for obtaining solidity in heavy sections. The gravity die can be "built up" thus facilitating venting at the parting lines, while a pressure die should be constructed of as few blocks as possible, otherwise the rapid heating and cooling, coupled with the mechanical effect of the injected metal, endangers die life. But providing the section is even and lies between $\frac{1}{8}$ in. —$\frac{1}{2}$ in. a pressure die-casting is capable of being practically free from porosity providing it is made in a high-pressure cold-chamber machine. Parts of uneven section, including heavy portions, are easier to produce solid in a gravity die-casting than in a pressure die-casting.
Design	Heavily undercut designs are possible in the gravity process and sand cores can be used for such complicated undercuts as that shown in Fig. 1. Sand cores are not employed in cold chamber pressure die-casting. In pressure die-casting, undercut designs such as that shown in Fig. 2 can be achieved, though generally the design is more limited.
Minimum Section	Since the metal is pressure injected, the pressure die-casting can be made thinner and therefore lighter than the gravity casting. Typical figures for minimum section are as follows :— *Small* *Large* Gravity die-casting .. $\frac{1}{8}$ in. $\frac{1}{4}$ in. Pressure die-casting .. $\frac{1}{16}$ in. $\frac{1}{8}$ in.
Range of Alloys	A greater number of aluminium alloys can be gravity cast than pressure cast. The majority of aluminium pressure die-castings are in aluminium-silicon or aluminium-copper-silicon alloys whilst almost any sand casting alloy can also be gravity die cast.
Maximum Weight	Gravity die-casting .. .. 120 lb. Pressure die-casting .. .. 17 lb.

Aluminium Alloys for Die-Casting

In addition to good fluidity, which is an obvious necessity for an alloy which is to be die-cast, alloys should not be hot short if satisfactory die-castings, free from cracks, are to be made. This latter need is particularly so in pressure die-casting on account of the stresses involved during rapid chilling in the water-cooled die. Consequently, as indicated in Table I above, the range of aluminium alloys for pressure die-casting is somewhat limited. The list given in Table II representing alloys which are regularly gravity die-cast, is taken from a paper by H. W. Fairbairn.[2]

TABLE II.

Specification :—	Common Designation :—
B.S. L.8	L.8.
B.S. L.35	Y alloy.
B.S. L.33	Alpax or L.33.
DTD. 133B.	RR. 50.
DTD. 304	NA. 226/T.92.
DTD. 165	Birmabright.
DTD. 424	D.7 or D.8.
DTD. 428	"Z" alloy (or 7–3–2 Alloy).

Fig. 3.—Group of aluminium alloy pressure die-castings for domestic washing machine.

Pressure die-castings are most regularly produced in the straight aluminium silicon alloy, L.33 (for preference) or (during the war) D T D.424, the aluminium-copper-silicon alloy. Some work has been done in the pressure die-casting of RR.50, though cracking trouble is difficult to overcome; it is, however, felt that the excellent mechanical properties of this alloy make it desirable that the pressure die-casting industry should add it to their repertoire. Other alloys which have been pressure cast are Birmabright, DTD.165, secondary L.33 (Intasil) and No. 13 alloy of which a typical analysis is as follows :—

Si. 11·9%	Cu 2·52%	Mn 0·28%	
Ni 0·44%	Fe 1·78%	Zn 0·4%	
Al—remainder.			

Table III is taken from an American book, "Die-casting for Engineers,"[3] and shows aluminium alloys which are pressure die-cast in the U.S.A.

In addition it has been reported to the writer that the aluminium die-casting alloys, given in Table IV, were developed by the Precision Casting Co., of America, to replace aluminium-silicon for uses in building and for domestic appliances. These alloys possess a whiter and more attractive finish than the bluish tint of the aluminium silicon alloys.

The first alloy is used where good strength is required, its tensile strength being 15 tons per sq. in. The second alloy polishes to an attractive finish and lends itself well

2 H. W. Fairbairn. Institute of Production Engineers, 1944 (November). Vol. 23, No. 11.

3 The New Jersey Zinc Co., "Die Casting for Engineers" (book). Printed in U.S.A.

TABLE III.

COMPOSITION AND PROPERTIES OF AMERICAN ALUMINIUM ALLOYS FOR DIE-CASTING.

Designation :—	IV	V	VI	VII	VIII	IX	XI	XII	—
A.S.T.M.	304	305	——	307	——	309	——	312	——
S.A.E.	43	13	83	85	——	93	——	81	218
Composition % :—									
Copper	0·6 max.	0·6 max.	1·5 to 2·5	3·5 to 4·5	1·0 to 2·0	3·5 to 4·5	1·0 to 3·0	6·0 to 8·0	——
Silicon	4·5 to 6·0	11·0 to 13·0	2·5 to 3·5	4·5 to 5·5	0·5 to 1·0	1·0 to 2·5	7·0 to 9·0	3·5 max.	——
Nickel	0·5 max.	0·5 max.	9·5 max.	0·5 max.	1·75 to 2·5	3·5 to 4·5	0·5 max.	0·5 max.	——
Aluminium	rem.	rem.	rem.	rem.	rem.	rem.	rem.	rem.	rem.
Iron max.	2·0	2·0	2·5	2·3	2·0	1·8	2·0	2·3	——
Zinc. max.	0·5	0·5	0·8	1·0	0·5	0·8	0·5	1·8	——
Manganese max.	0·3	0·3	0·3	0·3	0·3	0·3	0·3	0·3	——
Magnesium	0·10 max.	0·10 max.	0·10 max.	0·10 max.	0·10 max.	0·10 max.	0·10 max.	0·10 max.	7·5 to 8·5
Tin max.	0·1	0·1	0·1	0·1	0·1	0·1	0·1	0·3	——
Total other impurities, max.	0·2	0·2	0·2	——	0·2	0·2	0·2	0·2	0·2
Properties and Constants :—									
Yield Strength Tension Set 0·2% psi.	13,000	18,000	14,000	19,000	——	20,000	——	24,000	23,000
Ultimate Tensile Strength psi.	29,000	33,000	30,000	35,000	29,000	33,000	32,000	32,000	38,000
Elongation, % in 2 ins.	3·5	1·5	3·5	2·7	4·0	1·0	1·7	1·3	5·0
Charpy Impact, ft. lb.	4·5	2·0	5·0	2·5	4·5	2·0	3·0	3·0	10·0
Brinell Hardness No.	60	80	60	70	60	80	——	70	——
Specific Gravity	2·70	2·66	2·75	2·78	2·72	2·87	——	2·85	2·53
Weight lb. per cu. in.	0·097	0·096	0·099	0·101	0·098	0·104	——	0·103	0·091
Shearing strength psi.	18,000	22,000	19,000	22,000	18,000	22,000	——	26,000	——
Melting Point (Liquid Temp. °C.)	630	583	637	620	645	626	——	630	626
Thermal Conductivity, GGS Units	0·38	0·33	0·28	0·27	0·26	0·25	——	0·27	0·24
Thermal Expansion, in./in./°C.	0·000022	0·000020	0·000023	0·000021	0·000022	0·000021	——	0·000022	0·000024
Electrical Resistivity, microhm-cm.	4·2	5·9	5·7	6·2	6·0	6·6	——	6·2	——

TABLE IV.

Alloy	Cu %	Ni %	Si %
Precision A-24	5	2	2
Precision Alni No. 2	4	5	2
Precision Palmo	2	2	8

Balance—Aluminium in all cases.

to enamel and other treatments. The third alloy is reported to be very resistant to discolouration.

A likely Post-War Development

One development to which we may look forward after the war is the selection of an aluminium alloy which will pressure die-cast well, and which can then be anodised and tinted with attractive colours. The aluminium alloys which have been widely pressure die-cast can be protectively anodised but the film is of a greyish colour and tints applied to it are not so bright or clean as those produced after anodising aluminium with a low alloy content. Some of the alloys mentioned above, particularly those with low silicon content, have already been pressure die-cast, anodised and tinted with fair success, but we still need an alloy which will pressure cast as well as L.33 and which can then be anodised and tinted in attractive colours.

In America an aluminium alloy with 1·5%–2·0% copper, 1·5%–2·0% silicon and 2·25%–2·5% nickel has been used for pressure cast typewriter components, anodised and tinted to produce a pleasing rainbow effect.

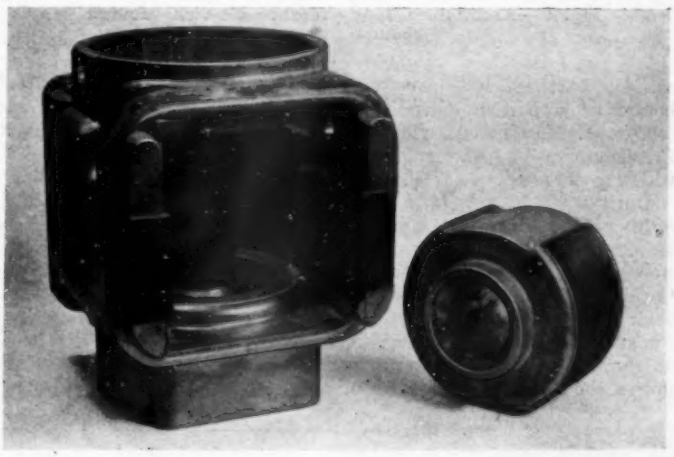
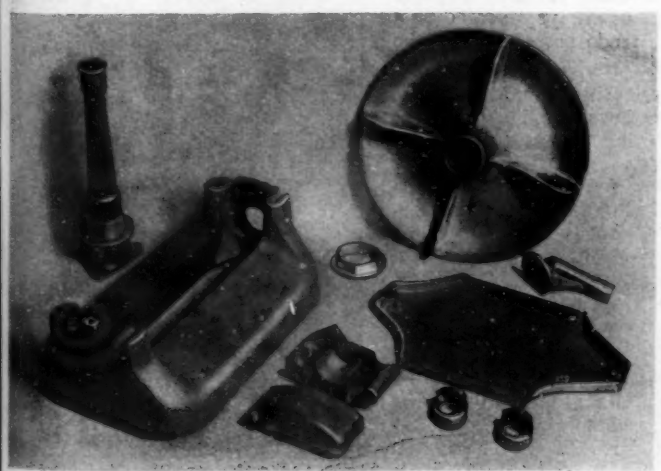


Fig. 5.—Aluminium pressure die-cast rotor and stator, illustrating use of inserts.

Fig. 4.—Group of aluminium alloy gravity die-castings.



Pressure Die-Cast Crank Cases

The die-casting industry has always been enterprising and this country can be proud of what has been done here, particularly during the war. However, the following account of an outstanding American feat of aluminium die-casting production may be worth recounting as a conclusion to this

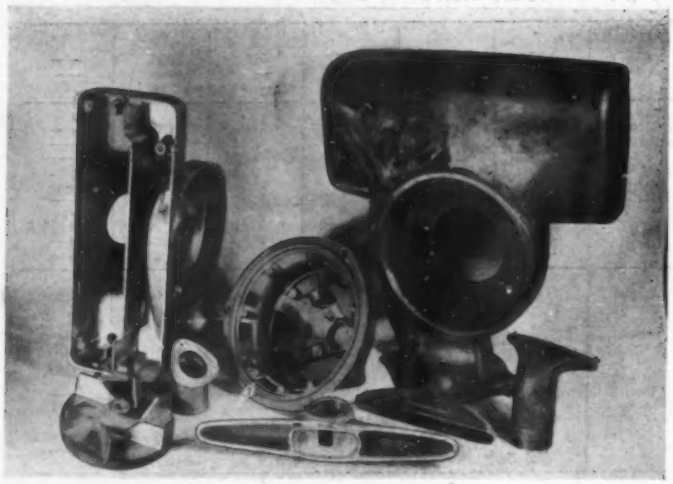


Fig. 6.—Aluminium alloy pressure die-cast vacuum cleaner components.

article, particularly since it has not been printed before in a British journal. The writer is grateful to Mr. J. M. Hutton, who was chief metallurgist of Precision Casting Co., Inc., for giving the information which appears below.

During 1933 and 1934 the American automobile industry had often contemplated using pressure die-cast crank cases, but generally more conventional methods were eventually used. However, in 1934, the Auburn Co. decided to order a pressure die-cast crank case for their 12-cylinder model, though they apparently doubted the success of the die-casting. The contract was placed on the understanding that no payment should be made unless the Precision Casting Co. produced satisfactory samples within four weeks of placing the order. Since the casting weighed about 13 lbs. and the die weighed about 4 tons, the magnitude of the task can well be imagined. During a week-end conference at the Precision factory the "plan of action" was approved, and by Tuesday the die blocks had been forged and were on their way to the die-caster. Incidentally, such was the promptness of delivery that the die blocks were loaded hot and the lorry caught fire *en route*.

The die making was organised to proceed in shifts with junior tool makers attending to semi-skilled features of the die making and senior tool makers working in the actual die cutting. The heat-treatment of the two 2-ton die blocks was carried through successfully and under the allotted four weeks the first sample die-castings were being made on a goose-neck machine. The size of the die was so considerable that it has to be erected on the machine with its length at right angles to the axis and a special melting pot had to be fitted at the side of the machine. Not only were the samples approved, but the full quantity of 10,000 crank cases were delivered to the satisfaction of the purchaser. In addition to the problem of bulk, the crank case involved certain design features which were then new: It contained baffles to prevent the surge of oil as the car rounded bends at speed and an oil return pipe was cast as an inherent part of the die-casting.

It is perhaps a good thing that all our die-casting feats are not so adventurous as this one, but it is certain that while the industry possesses men who are able to undertake what appears to be the impossible, die-casting will continue its progress.

Wrought Light Alloys Development Association

THE Wrought Light Alloys Development Association was founded early in 1941 by the principal manufacturers of wrought aluminium alloys, with the object of providing a centralised source of information on the properties, characteristics and uses of the products of the companies concerned. The Association was envisaged and has always operated as a *technical* organisation entirely distinct from the trade association of the industry.

Although the Association's work has of necessity been almost entirely directed towards assisting the war effort, it has been possible to devote little time to post-war possibilities, particularly during the past few months. Special mention may be made of the Association's work on the Ministry of Works' Study Committee set up to deal with non-ferrous metals in post-war building and in the possible application of aluminium alloys in pre-fabricated houses, such as the Portal bungalow. These activities have, however, barely touched the fringe of post-war development work, and it has not been possible for example, to commence any appreciable amount of work in the fields of transport, marine applications or general engineering. The staff has continued to be built up as circumstances have permitted, to deal with increased enquiry work.

The general policy of the Association is directed by the Council under the Chairmanship of Mr. Horace Clarke (James Booth and Co., Ltd.) whilst the detailed direction of the Association is carried out by the Management Committee under the chairmanship of Mr. H. G. Herrington (High Duty Alloys, Ltd.).

Mr. Horace W. Clarke.

The Coinage Metals in Antiquity

Part III.—Asia Minor, Phœnicia and South Russia

By Douglas Rennie Hudson, B.Sc., Ph.D.

(Lecturer in Metallurgy, Heriot-Watt College, Edinburgh.)

"Son of man, say unto the prince of Tyrus : . . . with thy wisdom and understanding thou hast gotten thee riches, and hast gotten gold and silver unto thy treasures : by thy great wisdom and by thy traffick hast thou increased thy riches, and thine heart is lifted up because of thy riches." EZEKIEL.

"The fineness of this jewellery enables us to appreciate the creative genius of the Greek goldsmith in the fifth and fourth centuries B.C. *. . . The gold and silver vases are various and beautiful. It would be a long task to enumerate all the classes of Greek objects yielded by the ruins and cemeteries of the Greek cities [in South Russia]."* M. ROSTOVTZEV.

ABSTRACT.

A critical review of metal extraction and craftsmanship since the third millennium B.C. under the heads :—

1. ASIA MINOR.—Troy, *Gold and Silver, The Bronze-copper Anomaly ;* Thermi in Lesbos, *Copper and Bronze, Other Metals, The Aegean Islands as Stepping Stones ;* Anatolia, *Lydian Metallurgy, Hittite Metallurgy, Other Races.*
2. PHŒNICIA.—Chronology ; Early settlement, *Sidonian Period, Tyrian Period, Assyrian Conquest, Punic Colonisation ;* Phœnician Characteristics, *Industrial Activities, Lack of Cultural Attainment, Mercantile Exploration ;* Cornish Tin Traffic ; Metalliferous Mining in Spain, *Silver, Other Metals ;* Scripts—Invention of the Alphabet ; Phœnician Metallurgy, *Bronze, Ras Shamra, Byblos.*
3. SOUTH RUSSIA.—South-eastern Steppes, *The Steppe Roadway, Hellenic-Scythian ;* Kuban Valley, *Metal Craftsmanship.*

In the plateau of Asia Minor, metal technology in gold, silver, bronze and iron was consistently excellent from the third millenium B.C. Artistic attainment was not so good, and the products were exported by barter, both as raw materials and as manufactured goods, to neighbouring countries. Craftsmanship diffused outwards via the Aegean islands into Thrace, Attica, Italy, and into the Kuban. Culturally, the Phœnicians were mediocre, but they were shrewd traders and magnificent sailors, and developed metalliferous mining extensively, in Cyprus, Sardinia, Andalusia, and engaged before the fifth century B.C. in the Cornish tin trade. In South Russia a succession of irruptions led to a hybrid and vigorous metal culture influenced from Asia Minor, before 2000 B.C. ; later, about the fifth century B.C., Greek influence modified by Scythian, was predominant in metal craftsmanship. Probably the gold was imported from the Altai Mountains in Siberia.

6. ASIA MINOR

As in the Punjab and Baluchistan, excavation in Asia Minor has been sparse, and until recently it was sporadic, nevertheless the few sites that have been investigated have yielded results important in indicating the continuity of diffusion from Asia to Europe via the Aegean and Macedonia. Geographically it is quite continuous with the Iranian plateau ; politically it comprises the Caucasian republics of Russia, Turkey in Asia, a compact geographical component, part of Syria which includes Phœnicia and merges into the ancient nucleus of Assyria. It merges into Persia through the ill-defined regions of Armenia and Kurdistan. Practically the whole area is composed of high mountain ranges and includes the genesis of metal extraction.

Troy

Strictly, Troy comes within the ambit of Anatolian culture, but so greatly modified by neighbouring civilisations that until recently it was regarded as an outpost of the Aegean area. In fact, however, the current of diffusion here flowed strongly westward. Its central position and flourishing trade rendered it particularly susceptible to external influence.

Deposits at Hissarlik, the citadel of Ilium, were amongst the first to be investigated thoroughly. It is unfortunate that the industrious pioneer SCHLIEMANN was concerned with removal of a great volume, and recovery of a maximum number of objects of artistic interest, rather than with the careful recording, reporting, and photography regarded as essential to-day. His success was patent in the wealth of artefacts recovered, yet the pre-historian is far from satisfied. Excavation technique was as yet rudimentary, reports were written at Athens, far distant from the site, and after a long time had elapsed, from memory rather than notes. As many as ten layers have been identified, and the results are conflicting. The obvious conclusion is that objects have been mixed, but it is not certain that this is justified. In the circumstances the surprising thing is that the results are not more chaotic.

From the walled city Troy I little metal has been recovered, but monumental structure flourished. In II, the "Burnt City," estimated at 3000–2000 by FORRER, 2500–2000 by DÖRPFELD, 2400–1900 by DUSSAUD, spear heads and vessels in bronze, silver and gold were unearthed, as well as crucibles and moulds. Many of the metal objects were imported, and resemble those of the Danube Valley. III, IV, and V together make up 13 ft. Modern critique shifts Homer's Trojan War to Troy VIIa from VI, which is attributed to 1500 B.C. Previously Dörpfeld associated VIII with Greek *Ilion*, from 700 B.C., IX with Roman *Ilium* 500–0 B.C.

Gold and Silver.—In Troy II gold wire, foil, beads, spiral and soldered work were recovered, with vessels of gold, silver and copper. 10 cm. bars of gold, notched for subdivision in commercial transactions, and tongue-shaped

ingots of silver 975 fine also occur. The metal artefacts show skill in hammering, welding and sawing. Achievement was high, in working, extraction and alloying, but perhaps not so fine artistically as in Sumer, Elam or Egypt. ROBERTS-AUSTEN and GOWLAND thought that the metal was purified by cupellation, with a fineness of 950 as target; 3½% copper was added with about 1% of iron, lead and gold. Such a "silver" would have good working and mechanical properties.

The Bronze-copper Anomaly.—The level at which iron was first found caused a great deal of controversy, and the occurrence of copper even more. Needles and a knife of ferrous copper containing about 1% iron were reported by ROBERTS from Troy I. In Troy II bronze with 5–3% tin was common in razors, needles, axes, chisels, *cast in flat open moulds*. Later the standard 12–10% bronze, common in Irak in the fourth millennium B.C., was introduced. But, surprisingly enough, by Troy VI the tin content was again less. External provenance from inner Anatolia of the 10% bronze—which undoubtedly occurred—is probably the explanation of this anomaly. In earlier layers a Bronze Age following Neolithic, without intermission of a Copper Age, has been postulated previously by DÖRPFELD.

Thermi in Lesbos

Thermi, on the island of Lesbos, has been excavated with the utmost care by Miss Lamb. In comparison with pottery and bone artefacts the site yielded little metal. Five layers were proposed, dated provisionally :—

I–II, 3200–3000 B.C.; IIIA and IIIB, 3000–2800 B.C.; IV and V, 2800–2400 B.C.

This dating is incongruent with Frankfort's, and Miss Lamb concludes that Thermi V ended before Troy II.

Copper and Bronze.—Nearly all the metal objects were tools; drills, punches, pins, chisels and hooks were found, and the metal culture appears to be wholly utilitarian. Of 26 analysed by DESCH with great care all but four were of copper, either pure or modified with iron, arsenic, lead or nickel, usually not exceeding 2½%.

Of the true bronzes, one with 13% tin was attributed to Thermi I, and a spear head with 10% to the Early Bronze Age. A dagger with 16% and an arrowhead with 8% is dated at 1400–1200 B.C. Apart from a statement that the coppers modified by tin are not to be regarded as bronzes made by intentional alloying, Desch draws no conclusion regarding the assays, and in view of the variation any systematisation would be difficult. But the 13% bronze as early as Layer I seems significant to the author.

Other Metals.—One small specimen of gold in Thermi I and a small fragment of silver wire in Thermi IV were found. In the latter level two very unusual objects were recovered, a plain lead-rich soft metal bangle, and another bangle of almost pure twisted tin wire; these seem to be the only metal jewellery.

Crucibles and moulds were also unearthed.

The Aegean Islands as Stepping Stones.—So far as a general conclusion is warranted, the data seem fully to support the assumption that this island at least did act as a stepping-stone for Anatolian culture in its penetration to Europe. Such a diffusion has long been assumed for Troy, whose civilisation was more advanced in time. Copper pins with rolled heads and battle-axe heads confirm the diffusion from Asia Minor. After Thermi V a hiatus occurred until about the Middle Bronze Age—is this attributable to drying up of the supply of bronze from exhaustion of Persian deposits?

Anatolia

Lydian Metallurgy.—Lydian culture may be older than even Hittite, but we have few of their metal objects, and those mainly of late date. This may be accidental, but more probably because they had no metal tradition. Their invention of coinage—if we accept HERODOTUS' statement—is itself sufficient to give them an honourable place. *They were the first men known to us to coin and use gold and silver currency.* (I, Chap. 94.) The Lydians have also been credited with invention of the touchstone —γίθος Λυδή of Theophrastes and *lapis Lydus* of PLINY—termed βάσανος (basalt) by ARISTOTLE. King Croesus was the first to strike gold staters, and forbade the use of electrum for coinage. Since this alloy had no definite fineness a statutory ratio of 10 against silver was established, compared with 13⅓ for gold. Herodotus describes how, to win the favour of the Delphi oracle, King Croesus melted down a vast store of gold to make ingots (ἡμιπλίνθια = half-bricks), of which the longer sides were of six and the shorter of three palms' breadth, and the height one palm. Four of them were of refined gold (ἀπεφθοῦ χρυσοῦ or *aurum recoctum*), each weighing 2½ talents, 113 others of gold with silver alloy (λευκοῦ χρυσοῦ = white gold), each of 2 talents weight. He ordered a figure of a lion weighing 10 talents to be made of refined gold (I, Chaps. 51–52). In return for a gift of gold the Lacedemonians "*made a bowl of bronze graven outside round the rim with figures and large enough to hold* 2,700 *gallons.*"

Hittite Metallurgy.—The sturdy mountain Hittites (Chatti) from Cappadocia, who overthrew the first Babylonian dynasty in 1926 B.C., were unable to hold their gains under attack by the Kassites, and had to retreat to their hill fastnesses. Nevertheless, their influence was wide and persistent, not only on the inheritors of their empire—the kingdoms of Lydia and Phrygia, but in Assyria, Babylonia and even Susa.

Their history is known only imperfectly. Probably of mixed origin, with Babylonian and Indo-European components, they settled in Asia Minor from north Mesopotamia about 2500 B.C., displacing a rich indigenous civilisation. Prehistorically their red-figured pottery was frequently used as trade goods in the near east. They wore long, heavy, woollen mantles, hung from the shoulders. They showed some technical competence in sculpture, though their bas-reliefs nowhere approached the fine modelling of the Old Kingdom in Egypt, the Assyrian work and the later Persian tile work, with its brilliant glazing in colour.

Their military organisation was efficient, and imperial expansion reached its zenith about 1500 B.C. It extended over Palestine, Babylonia and Syria, but gradually dwindled, until about the 12th century B.C. it crumbled under attack by Phrygians from European Thrace. Absorbing Hittite tradition and skill, their successors became very capable in extraction of silver and even iron.

Greek χλωρός chloros = greeny-yellow from which *chlorine* is named, is said to be cognate with Phrygian *glouros* = gold; since alluvial gold was frequently the pale greenish *electrum* there is no mineralogical incongruity in this hypothesis. χαλκος has been derived from Aramaic *chalchi* = copper, and from Phœnician *chalak* = to polish or work; χρυσος = gold, from Babylonian *churasu* via Phœnician *charuz*.

Fig. 22.—Silver rhyton, with fine horizontal fluting, from Armenia. Gems originally in the crest and eye sockets are now missing. Conventional wings, horns, crest, etc., are gilt. Height 10 in. Persian-Greek style, 5th century B.C. Compare Figs. 15 and 11, in gold.

Of all the near east peoples the Hittites were outstanding in ore extraction and alloying. They worked not merely native gold, but won silver, and even quicksilver from mines near Iconium ; the cinnabar (*minium*, μίλτος) of Sinope was second only to that of Almaden in Spain. It is conjectured that much of the silver in the treasures of the Nile Valley, and the enormous amount used in Solomon's Temple, were of Hittite origin. Later, the mines contributed to the wealth of Croesus and of Darius. But of their many metallurgical accomplishments the summit was undoubtedly their success in producing sponge iron in quantity as early as the thirteenth century B.C. Both unwrought (*ferrum infectum*) and fabricated into daggers, knives, spear heads, and tools, this iron was bartered to contiguous foreign countries in exchange for dust and bar gold. Much of it went to Assyria, which employed it to good effect in its military conquests.

Of little cultural attainment, the Hittites spread their rich metallurgical heritage in many directions—Elamite jewellery, Assyrian military expansion from their iron weapons, metal extraction throughout Asia Minor, the replacement of Lydian *electrum* coinage by gold at the instance of King Croesus. This spread via Ionia through Magna Graecia to Rome, whose silver, bronze and gold currency is still turned up by the plough in the remote colony of Britannia after a lapse of two millennia.

According to Pauly-Wissowa (Encyclopedia of Antiquities) the oldest silver "coin" in existence carried the inscription of a Hittite (*sic*) king dated about 700 B.C. (?). It is in the form of a heel from a crucible. Before 1914 it was in the private ownership of a German pastor, while a copy was stated to be in a Berlin museum. Perhaps this is stretching a definition rather far ; nevertheless Lydia, where Hittite culture persisted strongly, has a powerful claim to the invention of a minted coinage—*viz.*, a rugged striated *electrum* blank, with weight and quality guaranteed by the impressed stamp.

Other Races.—Mitanni and Churri are sometimes included under Hittites, but they were really Subaraean in culture, non-Aryan in speech, and probably settled in Asia Minor at an earlier date. Round Lake Van, near Mount Ararat of the Old Testament, the Urartu produced first-grade bronze, as well as artefacts of gold, silver and iron. In process work they were good, extracting copper and iron from local ores. Some of their products were no doubt absorbed by Assyria and Babylonia, and survive to-day, attributed to the importing nations. Their language, recovered from inscriptions, is related to Georgian and not to Hittite. The Hittites, and probably other peoples in these highlands wore heavier dress than the Egyptians, Sumerians or Phœnicians living in a warmer climate, dyed red and blue. In Greek and Roman *quasi*-mythological tradition the Chalybes (χάλυβες or χαλδοι) troglodytes living to the south of the Black Sea, were credited with having been iron-workers from the dawn of tradition.

The fine Hittite tradition is also preserved in the accomplished metal craftsmanship of the Armenians, at a much later date, about the time of Alexander the Great. Compare the excellent horizontal fluting on the rhyton (a vessel with a large and a small orifice from which one could drink without touching it with the lips) in Fig. 22, with that of the golden ewer in the Treasure of the Oxus (Fig. 11). Winged horned animals were frequently used as pitcher handles in Armenian art (Fig. 12), and this treatment spread to the culture of the Kuban. While this style is first-rate from the artistic viewpoint, it is also very good from the functionalist. This silver rhyton, gilded at the horns, wings, crest, etc., was found at Erzingan, Armenia. It is nearly 10 in. high, in the Persian-Greek style of the fifth century B.C. ; gems formerly set in the eye sockets are now missing.

Mitanni, occupying a region at the head-waters of the Euphrates between Asia Minor and Assyria, are sometimes described as the true Mesopotamians. Their language was written in cuneiform, and amongst their gods were the Indian *Varuna*, *Indra*, and *Nashatianna* (Twins).

7. PHŒNICIA

Originally the territory of Phœnicia comprised a narrow (10–30 miles) fertile cultivated strip along the north-south coastline at the eastern Mediterranean. It included the coast of Syria and the beloved Sharon of the Jews. Commercial enterprise, maritime exploration, and colonial development were the outstanding characteristics of this Semitic people. Their settlements spread from Tarsus to Cadiz and throughout the Aegean. In the Mediterranean there is hardly a large island which they did not colonise—Cyprus, Crete, Malta, Sardinia, the Balearics—pushing out into the Atlantic, the Saragasso sea, the fortunate isles (Canaries) north to the

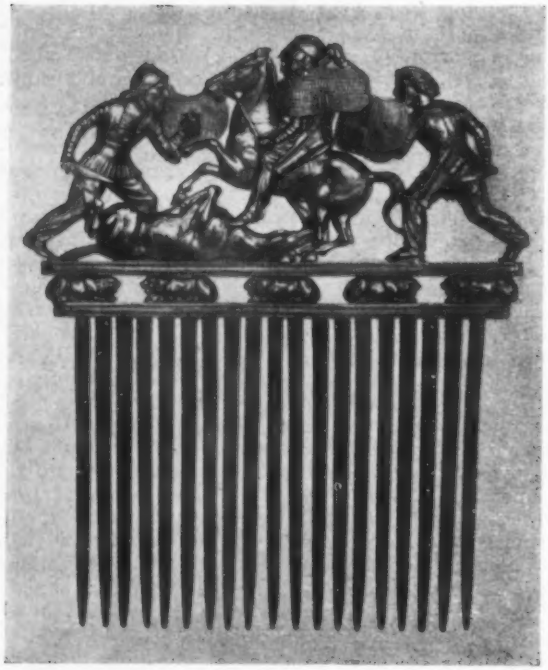


Fig. 23.—Comb of wrought gold from the Solokha barrow in the lower Dniepr valley. Note the fine balance of the pattern, the elan of the living figures, and the magnificent craftsmanship. Compare with Egyptian mummy pectorals at their best—Hellenic Scythian composite style, fourth century B.C. Hermitage Museum.

Scillies, and perhaps even to the Baltic. Thus it is wrong to regard their enterprising navigation as coast-hugging or island-hopping, although it was carried out without aid of echo-sounding, patent log, or chronometer. *C'est ainsi que peu à peu ils se sont enhardis jusqu'à aller chercher l'étain aux isles Cassitérides.*

Chronology

It is quite astonishing that a people credited with the world-wide distribution and even invention of alphabetic letters should have left practically no literature. Though inscriptions on stone and monumental engravings remain, they are microscopic in comparison with those of neighbouring countries. Nevertheless, the early history has been recovered to a remarkable extent, chiefly from Assyrian, Jewish, Egyptian and later from Greek sources. Not even a textbook of navigation, in which they were so skilled, or a common account book, survives.

Early Settlement

According to Herodotus, native tradition quoted 2750 for the foundation of Tyre. Byblos was an important Egyptian depot for cedar of Lebanon in proto-dynastic times, *circa* 2600 B.C., but it was an important commercial port many centuries before that. Semitic occupation of favourable sites on the coast probably took place about 2800 B.C. Tyre and Sidon rose to great prosperity and became proverbial for ostentation and wealth. They maintained an important commercial position as late as the medieval crusades—an astonishingly long record—and lost it only after Ottoman conquest in A.D. 1516. Under Egyptian domination (*c.* 1600–1350 B.C.) the country was regarded as a mere outpost.

Sidonian Period.—Later, a large measure of independence was obtained by the cities, and Sidon gradually became supreme until it was sacked by Philistines about 1180. Great progress in colonisation resulted from the introduction of night sailing, which halved voyage times. This was possible by steering by the pole star, indicated by the pointers of the plough (*Ursa Major*).

Tyrian Period.—Eventually Tyre gained predominance (1252–877 B.C.) and "long voyages" into the Atlantic began. Herodotus sceptically reports how King Neko (Νεκώ) of Egypt, 610–594, XXV dynasty, ordered the Phœnicians to circumnavigate Lybia (Africa) by sailing beyond the pillars of Herakles. This they did, returning in the third year, having sowed seed each autumn and reaped the harvest. By its very nature, the statement is favourable evidence for the circumnavigation, and is strongly supported by the historian's incredulity: "*. . . in sailing round Lybia they had the sun on their right hand . . . which some may believe, though not I*" (4, Chap. 32). Is it conceivable that the navigators would have invented a *prima facie* impossible story, or that they could ever have done so? Some two millennia later, Galileo was cruelly persecuted by the "Holy Office" for a theoretical *conjecture* much less revolutionary. The whole account supports the authenticity of "the Father of History," who on other counts has been attacked as a credulous and kindly old babbler, and shows the open-mindedness characteristic of Ancient Greece.

Friendly diplomatic relations with Judah are frequently mentioned in the Old Testament. *Hiram came out from Tyre to see the cities which Solomon had given him; and they pleased him not. And he called them the land of Cabul* [*i.e., scrap*] *unto this day. And Hiram sent to the king sixscore talents of gold.* One Babylonian talent (heavy) = 60 kg. In the tenth century B.C. a commercial treaty was arranged, grains, wine and oil being exchanged for the services of Phœnician artificers in building the Temple. Attributed copies of the diplomatic notes exchanged are still available. *Once in three years came the navy of Tharshish* [Andalusia] *bringing gold and silver, ivory and apes and peacocks* (*tukkiyim* = guinea fowl); these three were doubtless obtained from Africa. *And the navy also of Hiram, that brought gold from Ophir, brought in from Ophir great plenty of almug trees and precious stones.* King Hiram reigned *circa* 970–936 B.C., contemporary with Solomon. The location of Ophir has caused much dispute, perhaps most interesting is its equation with ἄπυρος (Gr. unfired or native) and not with a region. The almug tree was probably Indian sandalwood.

Assyrian Conquest.—About 877 B.C. Phœnicia accepted the suzerainty of Assyria, but expectations of lenient exaction were not fulfilled, and after an intermittent struggle lasting forty years was brought into subjection by Shalmaneser III (see Fig. 21), to whom tribute was paid in ingots of silver, gold, copper and lead.

Punic Colonisation.—Carthage, the "new city" was founded as a satellite of Tyre, to which tithe of revenues was contributed, towards the end of the ninth century B.C. Other districts, particularly Sicily, were colonised about the same time, but in Carthage the pioneering spirit of the motherland flourished greatly, so that the daughter city was soon in a position to found her own

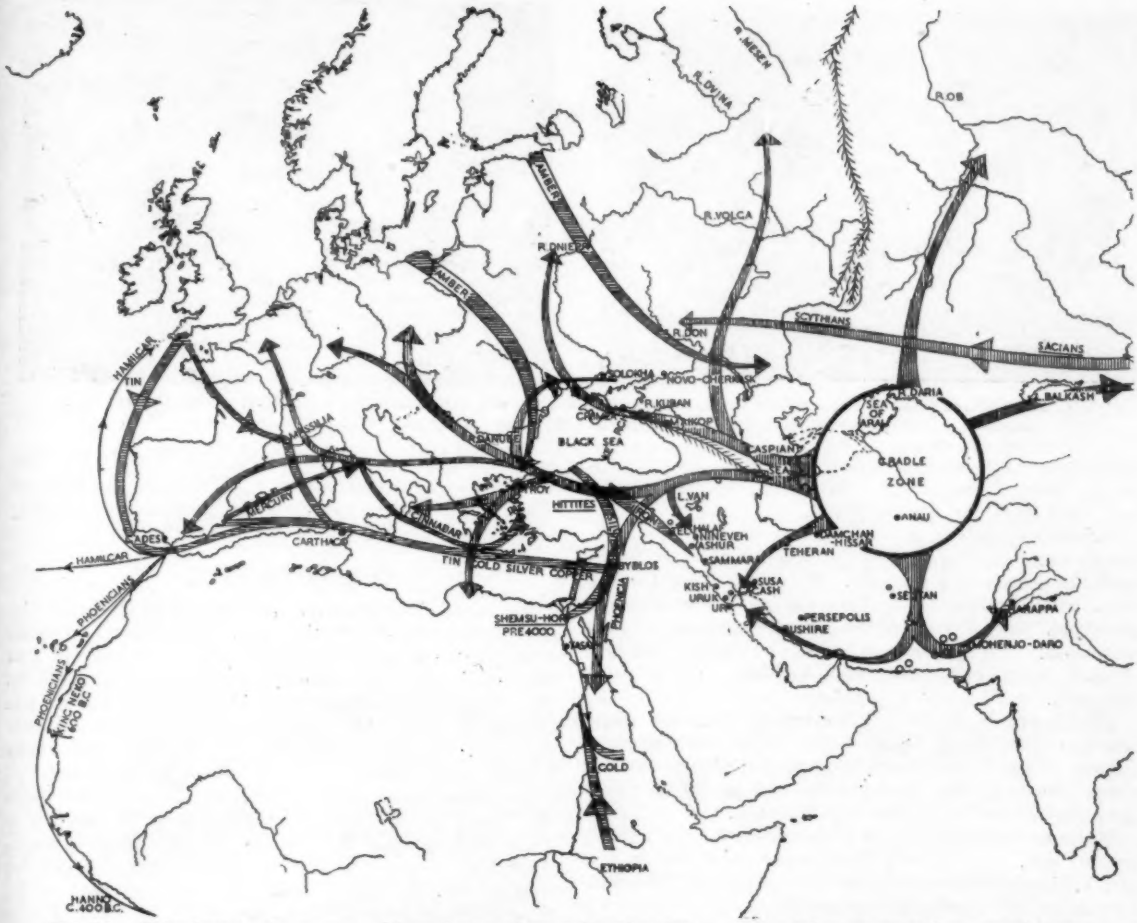


Fig. 26.—Principal trade routes and conjectured racial migrations. Phœnician exploration voyages are shown black. Trade routes are denoted by horizontal hatching, racial migration by vertical. In many cases, owing to gradual penetration, the cultural effect far exceeded the limits of the arrows on the diagram.

settlements. However, relations were consistently friendly, and help was sent to the homeland when the latter was hard pressed.

At the behest of the Punic senate Hamilcar sailed as far as the Scillies and the Saragasso ; and Hanno's voyage beyond the pillars of Herakles, southwards round Africa, with 30,000 souls in sixty 50-oar ships, is well known, though its date is doubtful, possibly about 400 B.C. Herodotus did not mention it, Strabo believed it fabulous. A colony, Thymiateria, was, however, described in the fourth century. A lucid text in Greek is extant, and the voyage doubtless occurred, though the figures may be exaggerated.

Success as a colonising power inevitably attracted the jealousy of the expanding *Imperium Romanum*, and there was intense rivalry, until in 146 B.C. the hateful ambition of the Senate *delenda est Carthago* was attained, and the once powerful Phœnician colony became Roman.

Phœnician Characteristics

By nature the Phœnician was a peaceable individual, as might be expected in a community so successful in trading. Nevertheless he showed no scruple in subduing with the sword any barbarian community which resisted the peaceful penetration which he had come to regard as his right. His commercial morality was very high. Like the Quakers of the eighteenth and nineteenth centuries he succeeded in combining this with great shrewdness and mercantile acumen. In trading with savage peoples the mute barter system was described by Herodotus, but the Phœnician was everywhere noted for honouring an agreement. *For the Phœnicians, it appears, were of old clever at making discoveries to their advantage, and the Italians equally clever in leaving no gain to anybody else.*—DIODORUS 5, Chap. 37.

Religious Observance.—As amongst Semitic peoples generally, religious sense was highly developed. In addition to cruel sacrifice of human firstborn to the image of Baal, with all the outward rejoicing necessary to render the oblation acceptable, the licentious worship of the goddess Astarte was prominent amongst Phœnician religions. The men wore hair and beard long and curled like the Assyrians, in contrast from the Egyptians, who shaved their heads in a fanatical seeking after cleanliness in a hot climate, salubrity of the Nile priests being proverbial. Women were much attached to personal jewels—necklaces of gold, glass and stone beads. The Phœnician's dress resembled the Egyptian's kilt,

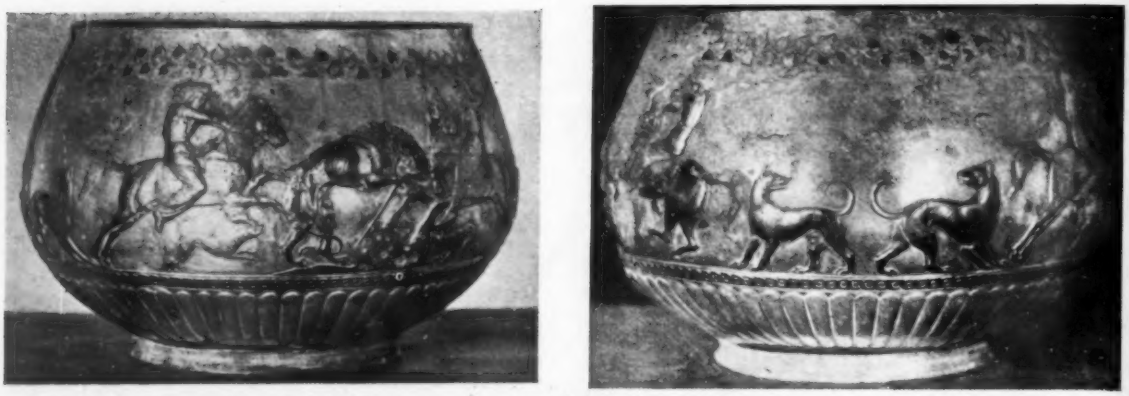


Fig. 24.—Silver goblet, showing in repoussé, mounted hunters, wolf-hounds and lion. The upper rim is enriched with an ivy-leaf border. Hellenic-Scythian composite style, fourth century B.C.

sometimes with a close-fitting jumper. In addition to fine linen from Egypt, they wore cotton fabrics, and wool from the Syrian sheep.

Industrial Activities.—Tyrian purple, familiar to fourth form schoolboys, was extracted from a sac in the molluscs *murex* and *purpura*. These were captured in traps baited with flesh, and resembling a lobster pot in principle. Large heaps of the crushed shells have been recovered. The dye was used without mordant, patterns showed good harmonies and brilliant results were obtained.

Pliny's attribution of the invention of glass to shipwrecked Phœnician sailors who built a fireplace of *natrum* blocks on the beach, is in no way impracticable; glass, however, was known and used in Egypt many centuries before Phœnicia was founded.

Harbour engineering was well conceived and capably carried out. In general, their architecture was robust and lasting, though a fondness for monolithic construction raised some unnecessary problems.

Lack of Cultural Attainment.—Their introduction of alphabetic letters, and the great part which the Punic wars occupy in classical education, led to a false glamour which enveloped all things Phœnician. In truth, their cultural accomplishments were negligible—a civilisation of honest, hard-working, unimaginative, daring merchant princes. Their art and sculpture is lifeless and stilted, their silver plate is decadent Iranian, showing modifying influences. At one time they were credited with having instituted metalliferous mining in their many colonial possessions or settlements, even in Cornwall; now it seems very doubtful if they did anything more than develop and "organise" existing workings. That this was done efficiently there is no shadow of doubt, as in the workings of Sardinia. There large heaps of lead slag have been identified, with lead pigs, and ingots of fire-refined copper weighing 62–82 lb. avoir.

They could show nothing approaching the logistic and mathematical insight of Hellas, the exquisite Sumerian and Egyptian jewellery, the complex metal extraction of the Lake Van peoples, nor the involved astronomical calculations of the Nile Delta and Babylon. In their colonies the level was higher.

Mercantile Exploration.—Thus their reputation rests on achievements in exploration, mercantilism and commercial development, but in these directions what a glorious and solid foundation they show, rivalling the trading embassies of Assyria, the heyday of the Genoese and Venetian republics, Spanish conquests in the New World, the successful Tudor imperialism of England and Wales, and the mercantile and diplomatic ascendancy of the trading cities of the Hanse league.

Cornish Tin Traffic

These dashing seafarers are commonly credited with the exploitation of Cornish tin. There is no evidence whatever to support this, but there is little doubt that they traded in this commodity from very early times. How early it is difficult to say. By the fifth century B.C. the traffic was well established, and a secret closely guarded. HERODOTUS wrote: *Neither do I know of any islands called Kassiterides from which the tin comes . . . nevertheless amber and tin certainly do come to us from the limits of the world.* According to DIODORUS, a Phœnician master deliberately ran his ship aground, decoying Roman pursuers, rather than reveal his destination. Dates estimated for the beginning of the tin trade vary from 2500 (HENNING) to 300 B.C.! By the fifth century B.C. it was well established, and probably existed many centuries before this. It is likely that at first there was an *entrepôt* in Gaul, in Brittany, or at Corbilon on the Loire estuary, and that this gave rise to the confusion of the Kassiterides with continental deposits which is shown by STRABO, DIODORUS and PLINY. The confusion was deepened by the great secrecy preserved. CONTENAU concluded that they consistently exploited the deposits nearest to hand—*Notre connaissance des plateaux de Perse et de l'Asie mineure est encore trop imperfaite pour que nous puissions nier dans ces pays l'existence de gisements d'étain utilisés aux hautes époques. Plus tard, les Phéniciens recueillirent l'étain qui était le plus à leur portée, sans doute celui de l'Etrurie, puis celui de l'Espagne, ensuite celui de l'embouchure de la Charante, et des rivières de Bretagne. Ce n'est qu'à la fin qu'ils abordèrent la Cornouailles.*

DIODORUS stated: *With great care and labour they quarry from the ground, which is stoney, the metal which is found in lodes in the inside of the earth. They then form it into cubical* (?) *pieces like knuckle bones* (ἀστραγαλι) *and transport it to a British isle called Iktis nearby.* An ingot identified with this, resembling two coat hangers placed back to back, was found in the sea at Falmouth and deposited in Truro Museum; it was 32 in. long and weighed 158 lb.

To be continued.

The Yielding Phenomenon of Metals

Influence of Speed and Loading Conditions

Part II

By Georges Welter

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The yielding phenomenon of metals, of importance in applied mechanics as well as in metallurgy, is not yet sufficiently understood. Besides a theoretical consideration, the various factors which have a pronounced influence on the yielding of metals such as the kind of testing machine with its load-indicating device, as well as the rate of plastic deformation of the specimen, have been investigated. In order to obtain additional results about the loading conditions of the specimen, a new direct loading machine with a special recorder was designed, and the stress-strain diagrams of this machine were compared to those of the rigid straining machine. Furthermore, the transmission of the loads from the machine into the test specimen without harmful secondary effects was studied by means of three types of newly developed universal joints which allow loading the specimen axially.

In order to understand the whole stress-strain diagram, an automatic time chronograph was designed.

Furthermore, the characteristics of the two types of machine, the rigid straining machine and the direct loading machine, were compared to each other during the static loading tests, as well as during the dynamic tests with the machine in normal operation. During these tests an artificial yielding effect was obtained by a relative displacement of the loading faces of the machines. Stress-strain diagrams were recorded under different loading conditions; diagrams showing a most characteristic difference between these two types of machines were obtained.

By means of a special device based on sliding friction between three plates screwed together, the dynamic behaviour during yielding of metals in both types of testing machines was analysed and interesting diagrams were recorded. The rigidity of the straining machine could be gradually decreased by inserting elastically stressed elements between the grips and the frame of the machine. In five different steps the characteristics of the rigid straining machine were gradually made nearly equal to those of the direct loading machine.

Comparative tests with usual extensometers measuring in different places the relative movements of the grips and the loading faces of the machine gave valuable indications about the reliability of these instruments.

The upper and lower yield-points of mild steel were studied in function of the speed between about 400 lb. and 20,000 lb. per min. These tests show that the lower yield-point is much more affected by high deformation speed than the upper yield-point.

Time-controlled stress-strain diagrams show in all loading phases important variations of the loading speed in the rigid straining machine and the straining speed in the direct loading machine. The difference between the two types of machines becomes especially effective by comparing the stress-strain diagram of duralumin test specimens tested shortly after quenching and showing a very characteristic yielding effect.

(c) Devices for axial loading

Amongst the devices necessary for an investigation on the yielding of steel and especially the study of different effects on the upper and lower yield-points, the most important factor seems to be the effect of gripping devices which transmit the loads on the testing machine into the test specimen. These devices must protect the test-piece from harmful secondary stresses, as flexion or torsion, and they must allow to load the specimen as axially as possible. This is not guaranteed by the usual gripping devices with spherical bearings as shown in Fig. 18. By using threaded-end specimens, as represented on the left in this figure and using the Peters-Templin extensometer, represented in Fig. 19, the results A and B (left side of Fig. 18) were obtained. The electric extensometer was fixed successively on two opposite fibres of the specimen at 180°, and each time the specimen was loaded not higher than the elastic limit. This was repeated twice under the best obtainable conditions, aligning the spherical specimen holders as well as possible, and under unfavourable conditions regarding initial eccentricity. This was 0·0009 in. for the test A, and 0·006 in. for B (Fig. 18), calculated from the slope of each diagram. For the test made with devices for shouldered-end specimens, according to the results in C and D (Fig. 18), the calculated eccentricities were 0·0075 in. for the best alignment of the spherical holders and 0·01 in. for unfavourable conditions.

Moreover, the harmful effect of eccentricities can be shown clearly by a numerical example. A test specimen of 0·05 in. diameter may be loaded to 10,000 lb., with an eccentricity of 0·01 in. Then the eccentricity of the load provokes an additional bending moment of—

$$\frac{Pec}{I} = \frac{10{,}000 \times 0{\cdot}01 \times 0{\cdot}25}{\frac{0{\cdot}5^4}{64}} = 8{,}000 \text{ lb.}$$

This means that in one fibre the specimen endures a load of 18,000 lb. and in the other, at 180°, only 2,000 lb. So one side of the specimen may be loaded beyond the elastic limit or the yield-point, while simultaneously the other side is stressed only far below this limit.

The way in which an eccentric load influences the yielding of mild steel is

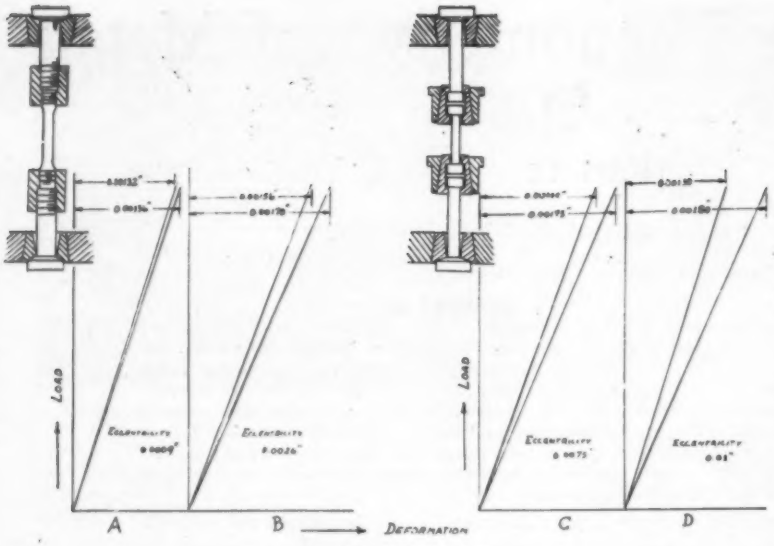


Fig. 18.

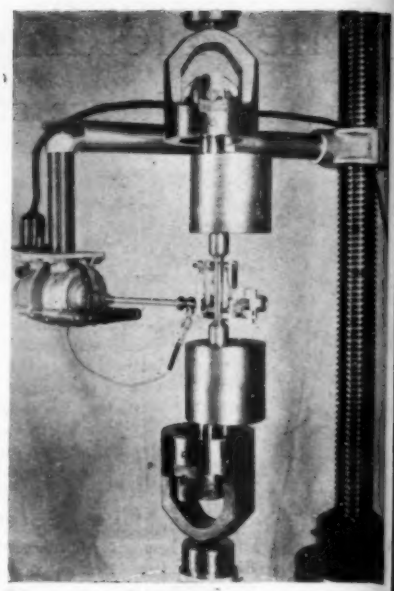


Fig. 19.

shown in Fig. 20.* At a perfect axial load the upper and lower yield-points of this material appear very clearly in the diagram A. However, if the load is applied with an eccentricity of $\frac{1}{8}$ in. according to diagram B, or $\frac{1}{4}$ in. according to diagram C, both the upper and the lower yield-points disappear completely and the yielding takes place during a longer loading period, starting at lower loads in *a* and finishing at higher loads in *b*, comparing to the axial tests. However, no other marked change took place during this test, having about the same properties in the pure elastic range *o–a* below the yield-point as in the plastic range *c–d–e* above this point. The diagram in these two parts is nearly identical to the axially loaded specimen A, Fig. 20. In order to avoid any eccentric loading and to be sure that localised yielding, due to stress concentration or to non-axial stresses, does not occur, it is necessary to provide the specimen with universal joints inserted between the heads of the specimen and the loading grips of the machine.

(1) *Universal Joints.*—To assure as far as possible complete axial loading during the tensile test, universal joints, based on different principles, were designed and built in the machine-shop of the Ecole Polytechnique. Three different devices were executed.

(*a*) *Universal Joints with Knife Bearings.*—This universal joint, designed for a maximum load of about 15,000 lb., is based on two independent central pieces A–B (Fig. 21), each one provided with two hardened steel knives in form of a V (C–C′–D–D′) supported by bearings E–E′, F–F′. These two main pieces are supported by an exterior shell G, which is fixed by its head H–H′ in the grip of the machine. The two central pieces can balance around the knife edges, which are fixed at an angle of 90°, so that the intersection of the lines of the knives coincide exactly with the axis of the test specimen, which is fixed in the smaller central part B. To illustrate the construction of this universal joint, Fig. 22 gives some views and sections of this device.

To control, if this device works satisfactorily, it was adjusted to two specially designed cylindrical blocks with axially and eccentrically drilled holes, as shown in Fig. 23. By means of this adjustment and an electrical extensometer, as shown in Fig. 19, the results represented in Fig. 24 were obtained. Diagrams A and B show the difference between axially tested specimen A and that one tested with an artificial eccentricity of $\frac{1}{8}$ in. in the steel block. For this eccentricity, we see that the specimen is elongated in one fibre an amount *o–a*, and shortens in the opposite side an amount *o–b*, diagram B, while for the axial load both fibres elongate *o–a*, on quite parallel line *o–a*, *o–a′*, and exactly in the same amount A. This means that the universal joint used for this test gives entire satisfaction by elimination of any eccentric load in the test specimen. On the other hand, the eccentricity for B, which is $\frac{1}{4}$ in. in the block, was found to be 0·27 in. true eccentricity, calculated according to the formula—

$$e = \frac{(a - b)\, d\,;}{(a \quad b)\, 8}$$

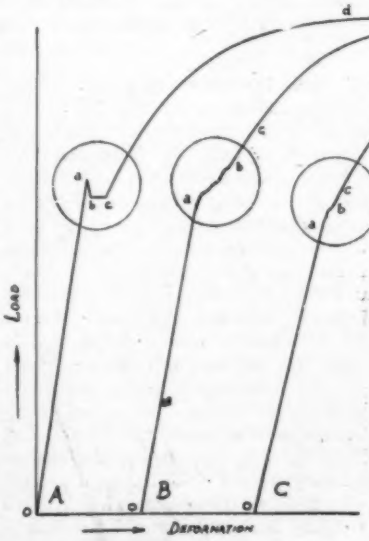


Fig. 20.

* Beginning from Fig. 20 all stress strain diagrams reproduced in this report are copies of original records registered by the different testing machines.

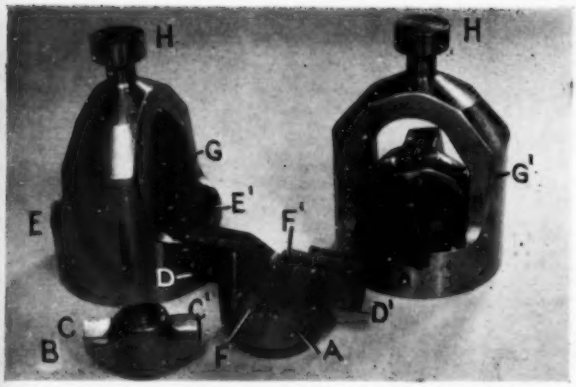


Fig. 21.

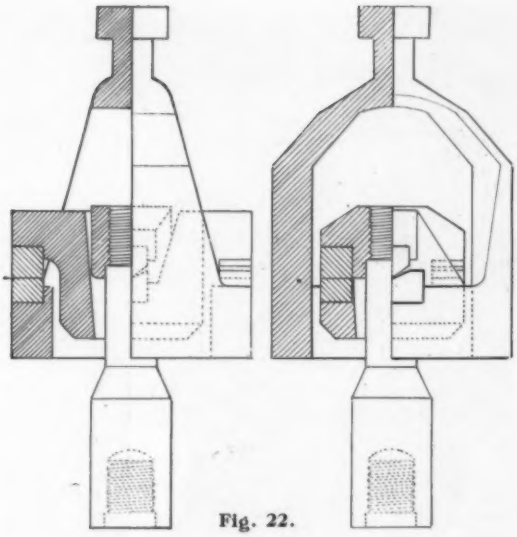


Fig. 22.

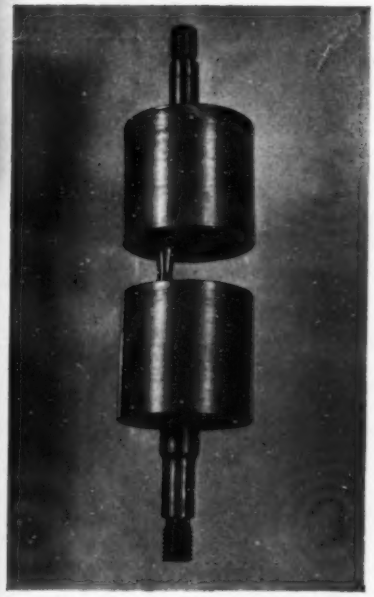


Fig. 23.

a and *b* are the deformation measured on the test specimen having a diameter *d* of 0·5 in.

Diagram C in Fig. 24 represents an extremely great eccentricity of $\frac{1}{2}$ in. in the block, giving 0.57 in. real eccentricity according to the measured tension *o–a* of one fibre and compression *o–b* of the other fibre of the specimen. These considerations are naturally only valid as far as the pure elastic deformations are concerned. If, however, an eccentric load is applied far beyond the elastic limit, so that the specimen can flow plastically and is able to readjust the local stresses over the whole section, then the real eccentricity in the test-piece rapidly diminishes, as shown in diagram D. Here are the results of a specimen of mild steel of 0·5 in. diameter loaded with an initial eccentricity of 0·27 in. and loaded the first time up to 12,000 lb.—that is, far into the plastic range of the material. After having unloaded and fixed the electrical extensometer anew on the test specimen, results according to diagram D are found. In this case the load, due to the plastic flow of the material, becomes nearly axial again, and an eccentricity of only 0·004 in. is left, calculated by the difference of the two extensometer readings *o–a* and *o–b*, as shown in diagram D. This diagram D is nearly alike to diagram A, where two extensometer readings followed the same line *o–a*, *o–a'* with the same elastic deformation. However, an eccentricity of $\frac{1}{2}$ in. made under the same conditions is no longer able to redistribute so completely the stresses in an equal manner over the whole section of the specimen, as for $\frac{1}{4}$ in. eccentricity. As diagram E (Fig. 24) shows, both fibres have positive deformation—that is, elastic elongation—but there is still a calculated eccentricity of 0·043 in. left. This means that by plastic flow in the range between the yield-point and the ultimate load the mild steel is able to reduce automatically the eccentric stresses appreciably, to the extent of becoming smaller than one-tenth of the initial values (from 0·57 in. to 0·043 in.).†

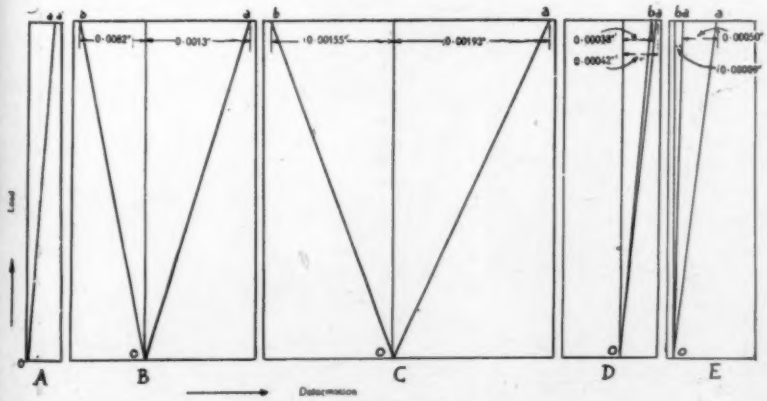


Fig. 24.

(*b*) *Universal Joints with Crossed Needle Rollers.*—With regard to the fact that axial loading of the specimen is of prime importance for reliable test results on yielding, another universal joint was designed, and this especially for smaller test-pieces and consequently for a lower maximum load. The universal joints shown in Fig. 25 are based on the alignment of the specimen by means of two crossed steel needles A. These needles,

† The tests about different eccentricities have been executed by Jean Trudeau, senior 5th year student at Ecole Polytechnique; for his assistance the author expresses here his best thanks.

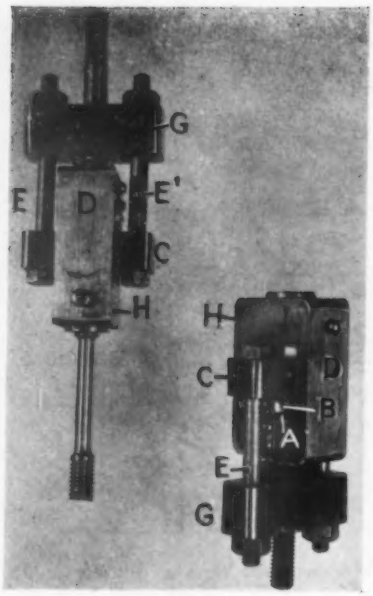


Fig. 25.

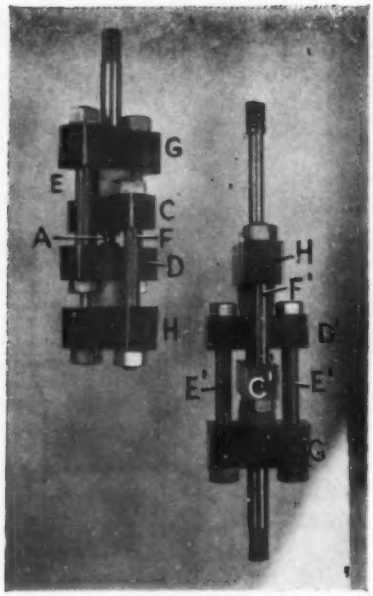


Fig. 26.

supported by a hardened circular plate B, transmit the load to two cross-pieces C and D, which are fixed by means of bolts E–E′ and F–F′ to the cross-pieces G and H. These cross-pieces are connected on one side with the grips of the machine, and on the other with the threaded head of the test specimen. This device, especially designed for the direct loading machine, is calculated to support safely a load of about 3,000 lb. Special stress was laid on the axial position of the crossing point of the needles and the centre of the cross-bar H in which the specimen is fixed. The results with this universal joint, as for the joint with crossed knives, were very satisfactory.

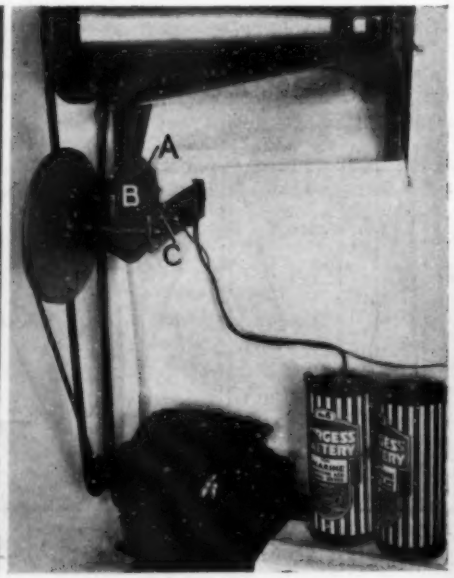
(c) *Universal Joint with One Point Bearing.*—In order to dispose of several universal joints, according to the loads needed for the investigation, another type of device designed for a maximum load of about 10,000 lb., and based on a somewhat different principle, was designed and built in the workshop of the Ecole Polytechnique. As shown in Fig. 26, this device guarantees an axial load of the specimen by means of a hardened steel ball A of about 10 mm. diameter. This ball is placed on two spherical seats B–B′, transmitting the load to the cross-pieces C–C′ and D–D′, which are connected with the bolts E–E′ and F–F′ to the cross-pieces G and H. These cross-pieces are connected on one side with the grips and on the other side with the head of the specimen. This universal joint is simple in its construction and permits axial loads, provided the ball with its bearing is placed in the geometrical centre of the test specimen. (Further tests with the universal joints concerning the axiality of the applied loads showed that they are not absolutely reliable. A certain correction regarding the position of each device in relation to the test specimen is necessary in order to obtain the best results.)

(d) *Device for Studying the Yielding at Critical Loads.*—According to the observations on the upper and lower yield-points, we know that after passing a critical load the test specimen shows suddenly a certain amount of elongation. Tests of this kind, executed with steel specimens on a rigid straining machine, show the characteristic dropping of the load during the first period of the yielding process. This peculiar behaviour of steel is not, however, an exception, but it is well known that other metals—as, for instance, duralumin and aluminium alloys, brass, copper and copper alloys, nickel and tungsten steels at certain temperatures, as well as a great deal of single crystals of zinc, cadmium, iron, copper and copper alloys show the same particularity. Test specimens of single crystals of those metals are very interesting from this point of view, because it can be expected that they will furnish a better understanding of the mechanism of yielding with an upper and a lower yield-point. In fact, investigations made by Schmid and Boas[8] on single crystals of cadmium behaved during yielding identically as mild steel specimens in their first yielding period. Due to the formation of twins at the critical load, these crystals show sudden changes in the

8 "Kristallplastizität," by E. Schmid and W. Boas, J. Springer, Berlin, 1935.

Fig. 27.

Fig. 28.



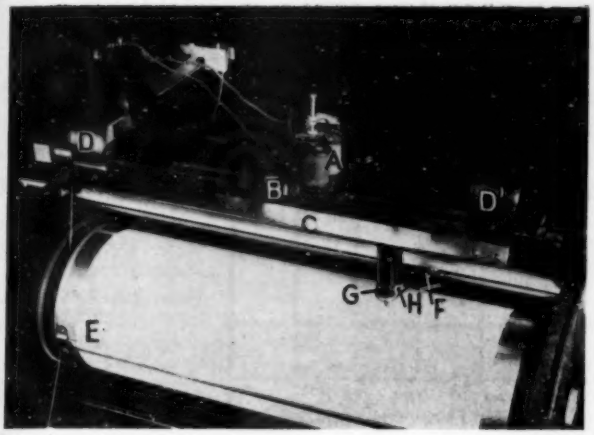


Fig. 29.

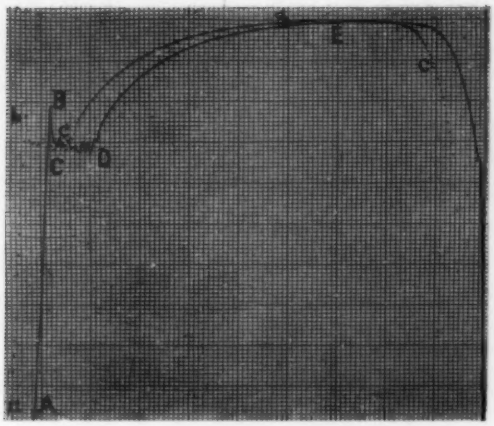


Fig. 30.

length, changes which are accompanied by an audible sharp cracking. At this moment the load falls suddenly down to a very small value. This process can be repeated with the same single crystals as often as these crystals permit the forming of twins by stretching. By this method, the conditions being simpler than those encountered in steel specimens with a very fine crystalline structure, it will be possible to get some more reliable information concerning the theory of the effect of the testing machine on the stress-strain diagram during yielding. As the single crystals of these metals are, however, somewhat difficult to make, and as they are not yet available in the form of test specimens of a size permittng the test to be made with the usual testing machines, it was thought profitable to find some equivalent substitutes for single crystals. To study these effects, a device represented in Fig. 27 gives, as will be shown later, the possibility to imitate quite naturally and very clearly the behaviour of single crystals during yielding by their special property of forming twins. This device, based on a mechanical principle, consists of three steel plates A–B–C of about $\frac{1}{8}$ in. × $1\frac{1}{2}$ in. × 6 in. screwed together with two transverse bolts D and E at both ends and connected with the grips of the machine. The middle plate B, by means of a fixture F, is fastened to the upper grip of the machine, while the two outside plates A–C are connected with the bolt and flat piece G and H to the lower gripping device. The plates are ground on the sliding surfaces and the bolts D and E transmit the load of the nuts through split washers to the outside plates, sliding on the inside plate of which the surfaces are oiled. If the bolts are tightened strongly, the loads which can be applied are fairly high. At a critical load, which is of the order of that of the yield-point of a mild steel normal test specimen, for instance, a sudden small sliding of the middle plate on the outside plates takes place, accompanied, as for single crystals, by an audible sharp cracking. Due to this sliding, the load falls down on the rigid straining machine, and, due to this decrease of the load, the sliding process stops immediately. If the load, however, continues to be applied it can again be increased, due to static friction between the plates; exactly the same sliding process takes place a second time, and this accurately at the same load and with the same increase in length of the device as for the first sliding. This process can be repeated a great number of times until the whole sliding length between the plates is exhausted. By unscrewing the plates and by pushing them together again, the whole process can be repeated as often as necessary without destruction of material. The initial friction between the plates, which is fairly high at the critical sliding load and which can be regulated by the pressure of the screws, falls down to the load necessary for the sliding friction. In this way a load-deformation diagram, nearly identical to that one of single crystals by twinning, or steel by initial yielding, can be recorded. Furthermore, by inserting, for instance, a small mild aluminium cylinder between the faces of the plates in the opening I provided in the middle of the three plates, a complete stress-strain diagram, similar to that one of mild steel or of single crystal test-pieces, can be recorded, as will be shown in Chapter D (*b*).

Fig. 31.

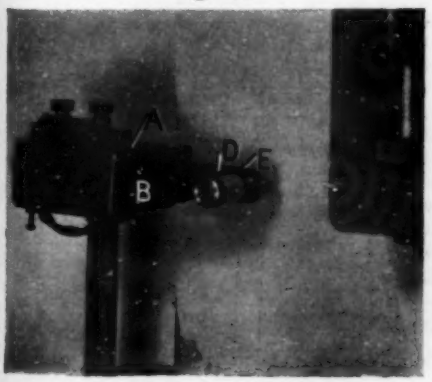
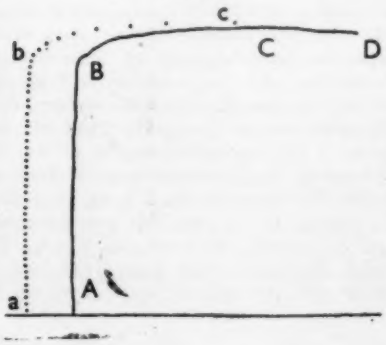


Fig. 32.



(*c*) *Autographic Time-recording Apparatus.*—It is a well-known fact that no test is complete unless, besides stress and strain, the time during which deformation takes place is accurately recorded during the whole deformation process. This is

Fig. 33.

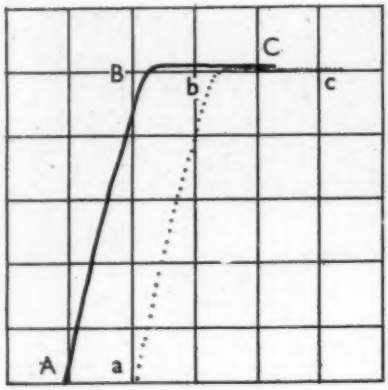


Fig. 34.

especially true for the investigation of those metals which show irregularities at the beginning of the plastic deformation. While it is simple to measure at the beginning of the test the rate of loading and stretching, it is rather difficult to make from the beginning of plastic deformation up to the end of the yielding period a record of the accurate values of straining as well as the stresses in function of the time. A few authors have investigated the effect of rate of deformation on yielding, especially on the upper and lower yield-point,[7], [9] based on the speed of deformation at the beginning of the test in the elastic range of the stress-strain diagram, or on the rate of loading in this range. It must be said that even if the speed of stretching and the rate of loading are well known in the elastic range, unfortunately in the region of the yield-point neither the deformation nor the loads are directly connected with these factors. Elastic deformation and the rate of loading in the elastic stage of the loading process seem to be completely unrelated to the phenomenon taking place during the yielding period. A variation of these factors will, and can, have only an indirect effect on the speed of deformation, and the variation of load in this period. Other laws than those of the elastic range of metals regulate the yielding of steel. It might be possible to gain more ground if the variation of load and the speed of deformation in function of the time were closely controlled during the yielding period itself.

For this purpose new devices were designed to record the time of the whole yield-point region, as well as in the elastic and plastic ranges of the stress-strain diagram. Up to date there have been made no attempts to grasp the phenomenon in the yielding period by a stress-strain diagram recorded simultaneously with a close control of the time. The apparatus described here will permit following the interesting phenomenon of irregular deformation during yielding in function of the stress in close relation to the time. For this purpose there may be fixed, besides the usual installation for recording the stress-strain diagram, a second recording device, which registers either mechanically, electrically or by means of pneumatic or hydraulic devices, a dotted time diagram from which the deformations of the test specimen in function of the time may be deducted. The time record can be made by points following in intervals of 1 sec. or a fraction of a second. It will be also possible to superimpose the time diagram on the stress-strain record, showing for every time interval a distinctive sign on the curve. In Fig. 28 is shown an automatic electrical chronometer. A motor-driven wooden disc A, reduced to 60 r.p.m., gives contact each second by means of the metallic point B and the spring C. A 6-volt dry battery sends a current to a small electrical magnet A, adjusted on the recorder of the testing machine, as shown in Fig. 29. This magnet transmits the movement of its armature through a lever B to a bar C suspended on a spring D. This bar is placed above the drum E of the recorder. On the pen carriage F of this recorder a second pen G is adjusted on a spring H, so that this pen does not touch the paper of the drum. This pen moves with a small interstice beneath the bar C. Each time the current passes through the magnet, the bar C strikes the top of the pen G, which records in this way a series of points opposite the usual stress-strain diagram A–B–C–D–E. As shown in Fig. 30, a series of points *a–b–c–d–e* recorded exactly each second, indicates the speed with which the test has been run. The rate of loading, as well as the speed of stretching, can be easily followed for each period of the stress-strain diagram. This method has the advantage that the autographic record made simultaneously with the usual diagram, tells the complete story of the static test. Especially critical values, such as yield stresses with the upper and lower yield-points in function of the deformation or the ultimate load and breaking stress, can be more accurately interpreted and discussed. This can be done without the possibility of error by detached observations on the rate of loading or the speed of stretching. After the test has been executed these two automatically plotted curves remain as a valuable document which can be consulted at any time about the behaviour of the material from the beginning to the end of the test.

An automatic time recorder used with the direct loading machine is represented in Fig. 31. This recorder is put into movement by the time controller, according to Fig. 28. It consists also of a magnet A whose armature B acts directly upon the small rod C placed at one end in a tube D, at which is fixed at the other end a pencil E at a small distance from the drum by means of a light spiral spring. An autographic record *a–b–c* registered with this device simultaneously with the stress-strain curve A–B–C–D is shown in Fig. 32.

A similar device for registration of the time during the stress-strain tests, as shown in Fig. 33, is fixed to the recorder of a 100,000 lb. universal Olsen machine, and Fig. 34 gives a reproduction of original records obtained with this recorder. All these autographic time recorders were built in the workshop of the Ecole Polytechnique.

To be continued.

7 E. Siebel and A. Pomp, *Mitt. Kais. Wilh. Inst. Eisenforschung, Düsseldorf*, p. 63, Bd. 10, 1928.

9 "The Influence of Rate of Deformation on the Tensile Test with Special Reference of the Yield point in Iron and Steel," by C. F. Elam, *Proc. Royal Society*, vol. 165, p. 568, 1938.

MICROCHEMISTRY
APPARATUS · METALLURGICAL APPLICATIONS · TECHNIQUE

WE recently pointed out that one of the main deterrents to the more widespread teaching of micro methods in ordinary chemical courses was the limitation imposed by the external examination. This difficulty has, to some extent, been surmounted by at least one Institution, Rotherham Technical College, which has taken the initiative in a highly commendable manner. The College was impressed by the success achieved in teaching micro methods to students in a specially designed course. This success was demonstrated publicly at a meeting last October, to which reference has already been made. Since the National Certificate course leads up to an internal practical examination, it was the obvious course in which to follow up the development of microchemical teaching. Rotherham, probably a pioneer in this country along this line, has, therefore, for some time been teaching qualitative inorganic analysis by micro methods to National Certificate students, not as a peep at a curious and difficult modern technique, but in the proper fashion, as a tool to be used with confidence by the students. Stated thus, the whole affair seems quite simple. But it must have required some courage on the part of those responsible for sponsoring the new development. Recognition of this is due, not only from microchemists, but from all those interested in the proper advance of chemical—indeed of scientific—education in this country. In particular, the Royal Institute of Chemistry could do much to acknowledge this by a pronouncement recommending the Rotherham experiment to the attention of similar institutions throughout the country.

The Chemist and the Microscope

Part I.—Inorganic Methods

By Cecil L. Wilson, M.Sc., Ph.D., A.R.I.C.

Chemical microscopy is one of the oldest branches of microchemistry and has many important applications in widely diverse directions. There is, however, some tendency nowadays to use its techniques only as a last resort, when, in some cases at least, they should be the first court of appeal. In this article, the methods and requirements of chemical microscopy are briefly discussed and some indication is given of the many ways in which it can be used.

THE usefulness of the microscope to the chemist was recognised by a few workers as long ago as the end of last century, the demand for instruction in its technique being sufficiently strong to warrant the publication, before 1900, of several text-books devoted to the study of chemical reactions under the microscope. As, however, reference is usually made to these in the many historical surveys of microchemistry which have appeared during the past ten years or so, and their existence is, therefore, well-known to the general run of microchemists, and probably also of ordinary chemical workers, it is not proposed in this article to enlarge further on the historical aspect of the subject.

The microscope is, of course, accepted as a routine tool in certain branches of industry allied to chemistry, such as in the examination of textiles, or in metallography. In these cases, however, it can hardly be said that we are witnessing *chemical* applications of the instrument. The directions in which we would be more likely to see a proper evidence of chemical microscopy are in the investigation of small scale reactions, more particularly as applied for analytical purposes, and the examination, both chemical and physicochemical, of small amounts of material. Many such processes are now well established, but it seems to be hardly so true to say that they are well known. Some reason for this may be found in the fact that the microscope is a relatively expensive instrument and requires for its handling someone with at least moderate confidence and experience. In the field, for example, of inorganic qualitative analysis, the development of spot tests which, in some cases, may require considerably less apparatus and experience for their application and interpretation, has undoubtedly prejudiced many analysts strongly in favour of the latter technique, and has led them to overlook the fact that occasions may occur when a microscopical test is less open to doubt. This prejudice may very well have been carried over into the other branches which make up chemical microscopy.

Instrumental Requirements

For general chemical work elaborate apparatus is not necessary. While much useful work can be carried out with an ordinary compound microscope the range may be considerably extended by the addition of the attachments usually available on a simple petrological microscope. To give the fullest advantages, therefore, the microscope should be fitted with a rotating stage, a polariser and an analyser. Nowadays it is possible to convert the compound microscope for use with polarised light by adding Polaroid discs, so that a reasonably good compound microscope should be regarded as a sufficient basis for practising quite a number of the techniques of chemical microscopy which would not previously have been feasible.

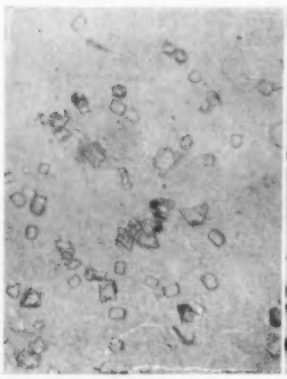


Fig. 1.—Barium sulphate on digestion with concentrated sulphuric acid. × 400.

Fig. 2.—Zinc tested with potassium mercuric thiocyanate. × 200.

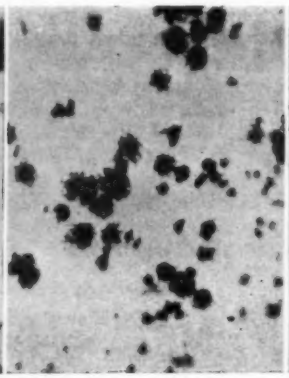


Fig. 3.—Cobalt. The dried test drop is flooded with potassium mercuric thiocyanate. × 200.

Fig. 4.—Potassium with uranyl acetate solution. × 200.

Low- and medium-power objectives, that is, 16 and 4 mm. (two-thirds and one-sixth inch) lenses are required, while it is preferable also to have available a 32 mm. lens for preliminary observations, and a 2 mm. oil immersion lens for high power work. Objectives for chemical work should have a large depth of focus. The working distance also, that is, the distance between the front of the lens and the object, should be as large as possible. This renders easy a certain amount of manipulation of the object, and enables some sort of protection to be supplied to the front of the lens when working with corrosive chemicals.

Two eyepieces will probably be sufficient. These should be of medium power, say giving a magnification of 10. One of them should be fitted with cross hairs whose position can be fixed, for use with the polarising equipment. The other one should be equipped to take some sort of micrometer scale, so that it can be used, in conjunction with a stage micrometer, for measuring purposes.

For most work a reasonably good long focus condenser is preferable. It should be possible to raise and lower this at will, but as the condenser is the least critical of the lens systems of the microscope, it is not necessary to specify it rigidly, except for precise high-power work. In this last case a condenser corrected for spherical aberration must be used.

The source of light for most chemical work can be supplied either by a north light for low-power work, or protect the eyes, for medium power. If the bulb has a condensed filament it can be conveniently converted for application to high power work.

An electrically heated hot stage completes the list of special equipment which is essential. Other articles, such as small burners, forceps, capillary pipettes and spatulas, can usually be contrived from material available in every laboratory, as required.

Inorganic Reactions

The methods of inorganic qualitative analysis are nowhere better described than in Chamot and Mason's Handbook[1] which is an essential reference book for anyone wishing to carry out the methods. Several aspects of this branch may be considered. In the first by a fairly strong electric bulb, suitably housed to place, the detection of single ions or confirmation of their presence is relatively simple in the majority of cases. The principle depends, of course, on the carrying out of chemical reactions on microscope slides in such a way as to produce crystals of recognisable and distinctive nature. Although frequently these reactions are modifications of those used on the macro scale, it is not always true that the best reactions on the larger scale are most suitable under the microscope. This is partly due to the fact that in the classical methods a low solubility usually indicates a more satisfactory product in a test. On the other hand, substances of low solubility usually separate in a very finely divided form which is not satisfactory for microscopical characterisation. As a general rule a reaction producing a substance of moderate solubility will prove more suitable in the latter case. An outstanding example of this point is the detection of barium, for which a solution of calcium sulphate is frequently used on the macro scale. On a microscope slide this reagent or dilute sulphuric acid will produce with barium a fine dust with no particularly recognisable characteristics. If, however, this precipitate is digested with concentrated sulphuric acid, characteristically shaped crystals will ultimately form. These crystals, which are not in general produced with calcium sulphate, are illustrated in Fig. 1.

1 "Handbook of Chemical Microscopy." 2nd Ed., vols. I and II. Chamot and Mason. (Chapman and Hall, 1938–1940.)

Choice of Method

Several methods of carrying out reactions on a microscope slide are possible, the particular one chosen being dependent on the test being carried out. Thus, in testing for zinc with potassium mercuric thiocyanate, a drop of the test solution may be placed on the slide, a crystal of sodium acetate added, and a drop of reagent solution allowed to flow into it by placing the two drops side by side and merging them. The crystals shown in Fig. 2 were formed in this way. If the same reagent is being used for cobalt, a satisfactory test is only obtained by evaporating a drop of the test solution to dryness and then covering the dried residue with a drop of the reagent. Small clusters of deep blue crystals, with occasional single tablets, will then form readily. They are illustrated in Fig. 3. This arises from the considerably higher solubility of the complex cobalt salt. In some cases the best results are obtained by addition of the reagent in solid form, while in others a conclusive test is only obtained by allowing the mixed test and reagent solution to dry out. The triple nitrite test as applied to detect small amounts of lead is a case in point. The test drop is first taken to dryness on a slide, and a small drop of strong acetic acid is added to the residue. In turn, a crystal of sodium acetate, one of copper acetate and one of sodium nitrite are added. With moderate concentrations of lead small black cubic crystals will form after a short time, but with smaller amounts of lead these will only be seen as the drop evaporates. As is necessary in a test of this class the crystals are readily distinguishable from the other crystals formed by the reagents on evaporation.

The detection of mixtures of elements while causing certain complications, is possible in many cases. Two procedures are representative. In the first of these identification is carried out after separation of the ions, a solution containing lead and silver ions being used for the test. A drop of this is precipitated on the slide with hydrochloric acid. No essential difference can be detected between the lead and the silver chlorides. On warming the drop lead chloride goes into solution and may be drawn off in a hair tip capillary. If the warm filtrate is blown out on another slide and allowed to cool, long needles of lead chloride will crystallise out. Further confirmation may be obtained by adding a little potassium iodide to the drop, heating to redissolve, and once more allowing to recrystallize. After a short time very characteristic yellow hexagons of lead iodide should appear, perhaps in conjunction with the white needles of lead chloride or the needle clusters of the double lead potassium iodide. In this connection it is worth noting that excess of potassium iodide should be avoided, otherwise none of the yellow lead iodide may be formed.

The silver may be confirmed by taking the residue of silver chloride up in dilute ammonia, and allowing the solution to crystallize slowly, *i.e.*, the drop being covered with a small crucible. Squares and cubes will appear after a time. Further proof of the presence of silver may be obtained by precipitating it with potassium bromide taking the bromide up in concentrated ammonia, and allowing it to crystallize slowly. Very characteristic hexagonal and triangular plates, which frequently show thin-film (interference) colours, will result.

Sodium and potassium may be detected by the use of uranyl acetate. If a test drop containing them is taken to dryness and a drop of concentrated uranyl acetate in strong acetic acid is added, clumps of needle crystals due to the potassium (Fig. 4), or small triangular crystals due to the sodium (Fig. 5), will appear after some time. In some cases the two ions may be detected by this reagent without separation.

The Testing of Mixtures

One point which must be stressed is that in many cases difficulties in interpretation may arise, which will only be surmounted by the analyst with a certain amount of training. In this respect an instructive experiment may be performed using dilute solutions of zinc, cobalt and copper, with, as reagent, saturated potassium mercuric thiocyanate. A drop of each of the solutions should first be tested in turn by adding a drop of the reagent. Zinc will give its characteristic white feathery crosses (Fig. 2), the cobalt salt may not separate or may ultimately give the characteristic clusters of deep blue prisms (Fig. 3), while the copper will form greenish-yellow needles and dendritic crystals, as shown in Fig. 6, or in certain cases tiny green crystals. If now a mixture is made of the copper and zinc solutions in the proportion of 1 to 10, brown or purple feathery crosses will result on testing. A solution containing copper and zinc in the proportion of 1 to 2 will, on the other hand, give tiny purple four-pointed crystals, which are illustrated in Fig. 7. A solution containing cobalt and zinc in equal proportions will produce the blue feathery crosses. Thus it will be seen that the result of a test will depend both on the nature of the ions present and on their relative proportions. As a consequence, both care *and experience* will be required in a case such as this.

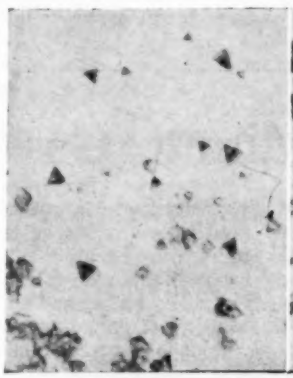


Fig. 5.—Sodium with uranyl acetate solution. × 200.

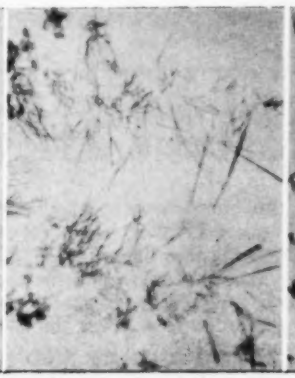


Fig. 6.—Copper with potassium mercuric thiocyanate. × 200.

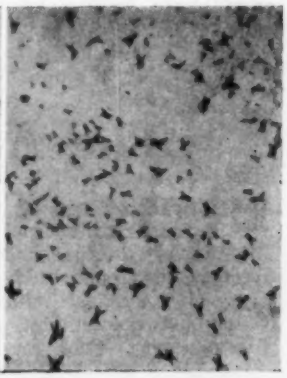


Fig. 7.—A copper-zinc solution (1 : 2) with potassium mercuric thiocyanate. × 200.

Schemes of Analysis

A step further in the handling of complex solutions leads us to the necessity for some sort of schematic detection. Whilst several schemes have been devised which will enable complete systematic analysis of alloys or other mixtures and final identification of the constituents through crystal tests, these are not completely satisfactory, and it is not altogether certain that they are desirable. In order to be efficient such a scheme calls for preliminary separation of the constituents of the mixture into small groups. Within these groups, reagents belonging to one of two classes are then necessary. The first class contains general reagents which will give distinctive simultaneous tests with a number of the ions within the group. But it is obvious from the consideration of the case of potassium mercuric thiocyanate, which has been presented here in a considerably simplified form, that such reagents must be chosen and used with discretion. The other reagents are specific, at least within their group. Unfortunately, the number of these so far discovered is limited. The tendency nowadays would appear to be to produce schemes which depend for final identification on spot tests only. But this is undoubtedly as open to objection as going to the other extreme and refusing to employ anything other than crystal tests. Some reasonable means should be possible which will make the fullest use of the two techniques. Although a great deal of work remains to be done in this direction, some compound schemes of this nature which are satisfactory in simpler cases have been proposed.[2] It seems reasonable to assume that it is preferable to employ a superior crystal test to an inferior spot test if the only drawback thus introduced is a change in technique. The test for nickel with dimethylglyoxine, for example, is unmistakable under the microscope, although as a spot test iron may in certain circumstances cause confusion.

Applications

In certain branches of investigation the crystal methods are preferable to any other variation. For the identification of mineral grains in rocks and ores, when used in conjunction with some of the physical methods to be described later, they are highly valuable, and are to be preferred to colour tests since magnification will probably have to be applied in order to observe reactions of any kind. Considerable application has also been made to the identification of inorganic constituents in plant tissues and other places where the location of the constituents is important and the area to be examined is small or microscopic.

2 "An Introduction to Microchemical Methods." Wilcox. (Methuen, 1938.)

The Analysis of Minute Gas Bubbles

DETAILS of one of the more spectacular and ingenious methods of microchemistry—a method briefly referred to in this Journal some time ago*—have recently been published†. The method is one for the analysis of small gas bubbles, enclosed in glass, and can be applied to volumes of gas down to a lower limit of 0·004 cu. mm. Such an analysis, involving the determination of five of the more likely gases to be encountered, occupies approximately one hour, and, with the exception of a microscope equipped with a micrometer eyepiece, all the apparatus is simple and easily prepared.

The volume of the gas bubble is determined by liberating it in a glycerine bath, so that it is trapped under a microscope slide, and then measuring the diameter of the bubble in terms of divisions of the micrometer eyepiece. The bubble is then transferred, using a specially designed micro-pipette, to other vessels or absorption pipettes, where it is subjected to the action of various appropriate reagents. It is then retransferred to the measuring cell, and the decrease in diameter of the bubble, and hence the decrease in its volume, is a measure of the volume of gas which has been removed by the absorbent. The gas bubble is washed thoroughly between each absorption treatment and measurement.

For the removal of hydrogen sulphide, the bubble is washed for five minutes with a solution of cadmium acetate in glycerine. Caustic potash dissolved in glycerine is used for the removal of carbon dioxide. The remaining reagents are made up in aqueous solution, so that more care has to be used in manipulation owing to the lower viscosity; and a rather different set of apparatus is used to render loss of the bubble less likely. Alkaline sodium hydrosulphide solution absorbs the oxygen, carbon monoxide is removed by ammoniacal cuprous chloride solution, and hydrogen is taken up by a colloidal solution of palladium containing sodium picrate. Any residue is assumed to be nitrogen, but it is obvious that where other gases were likely to be encountered, other reagents might be applied in like manner.

Certain errors are inherent in the method, *e.g.*, some of the gases are appreciably soluble in glycerine; and the bubble is not completely spherical, whereas the method assumes that the diameter measured is that of a sphere. These errors may be considerably reduced, if greater accuracy is required, by basing results on a series of standard known mixtures which are analysed by the routine procedure, thus furnishing a set of empirical corrections.

However, it is not surprising that an analysis of bubbles of the order of size dealt with is rather inaccurate—it is rather an achievement to be able to carry out an analysis of this nature with any sort of confidence in the results.

The method, then, though striking, is not merely so, but is also eminently practical; and there is no doubt that it is capable of considerable extension or modification to cover problems other than those of the glass industry.

In addition to the quantitative procedures quoted, the paper describes qualitative tests which may be applied to the identification of minute amounts of sulphur dioxide, hydrogen sulphide, and water vapour in gas bubbles.

* METALLURGIA, 1943, **28**, 303.
† Price and Woods. *Analyst*, 1944, **69**, 117.

Tensile Properties of Medium-Carbon Low-Alloy Cast Steels

By H. A. Schwartz and W. K. Bock

CAST steels vary in composition and frequently are used in various states of heat-treatment, and it is important to be able to predict the composition that might accompany specific engineering properties by suitable selection of heat-treatments. Results obtained in this investigation, which forms only part of a wider investigation, covering many other properties and which was indicated in an attempt to find any existing correlations between several observed phenomena, deals mainly with the relationship between tensile strength and elongation of a given steel in various states of heat-treatment. The yield ratio and its effect on hardenability is also discussed and some attention given to reduction of area and Brinell hardness number.

The tests were made on 25 heats, mostly of acid electric cast steel deoxidised with calcium silicide and aluminium. Three of the heats were basic open hearth steel and in other three heats titanium was used in place of aluminium. The various steels contained from 0·23 to 0·44% carbon, 0·28 to 0·58% silicon, 0·46 to 1·41% manganese, 0 to 3·35% nickel, 0·02 to 1·44% chromium, 0·02 to 0·47% molybdenum, 0 to 0·12 % vanadium, 0·03 to 0·81% copper, and included nickel-chromium, nickel-chromium-molybdenum and chromium-molybdenum steels. About 150 test bars were cast from each heat, roughturned to 1 in. diameter, heat-treated, machined to 0·505 in. diameter and polished. Stress strain diagrams were obtained for each test specimen and yield strength determined to 0·1% Brinell hardness determinations were also made.

Some 40 heat - treatments were carried out for each heat. These represented normalising from 900° C. and/or from 820° C., either untempered or tempered, at a series of temperatures beginning with 400° C. and advancing 100° steps to the last permissible interval below the known Ac_1 point; also quenching from 900° or 820° C. in the latter case, sometimes after preliminary normalising at 900° C., followed by a variety of quenches as before, but terminating at the first step above Ac_1. Typical heat-treatments were followed by ageing at 200° C. Additional small specimens approximately ¾ in. cubes were normalised and quenched and then tempered at successively higher temperatures to determine the lowest indentation hardness obtained on each of the several steels. Jominy hardness curves were also obtained on each steel. For each steel the tensile strength

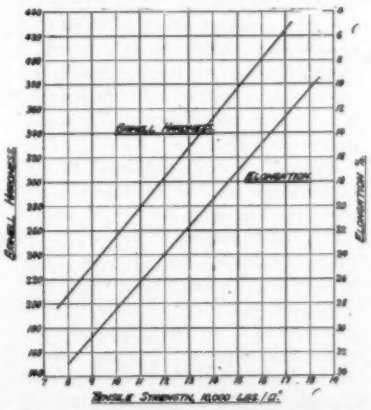


Fig. 1.—Relation of tensile strength to Brinell hardness and elongation of a single steel in various stages of heat-treatment.

For each steel the tensile strength elongation relation and the tensile strength-Brinell hardness relation were summarised in a graph similar to Fig. 1. The trend lines for each steel were then determined by record of its slope (a for elongation, x for Brinell hardness) and its interception the tensile strength or Brinell hardness (b and y respectively). The slope of the line of regression of elongation on tensile strength is represented by an equation for log a in terms of the various elements contained in the steel, and the intercept of the line (prolonged) on the line of zero elongation b by an equation of similar form with different values for the coefficients. These coefficients determined by least square calculation from the compositions of the various steels and their trend line values are given in Table I. The standard error for log a was 0·0745 and for b 1·431, the units of measurement being on 0·01% for concentration, 10,000 lb. per sq. in. for tensile strength, and 1% for elongation.

TABLE I.—COEFFLUENTS.

—	Log a	b	T_0	E_0
Constant ..	1·25262	5·18479	3·7798	50·467461
C	−0·01665	0·23237	0·0679	−0·627065
Si	0·00053	−0·00172	0·0162	−0·081446
Mn	−0·00096	0·02501	0·0159	−0·073307
Ni	−0·00094	0·01632	0·0047	−0·037237
Cr	−0·00055	0·01633	0·0095	−0·047877
Mo	−0·00505	0·07174	0·0196	−0·200159
V	−0·00064	0·04259	0·0119	0·075156
Cu	−0·00114	0·01841	0·0060	−0·031304

From the values of x and y the tensile strength T in units of 10,000 lb. per sq. in., corresponding to a given Brinell hardness B, follows from

$$T = Bx + y$$

The minimum tensile strength T_0 of each steel, Table I, was calculated and related to composition by least squares calculation, and the standard error of calculated and observed values of T_0 was 3,060 lb. per sq. in. Again by the least squares calculation, the minimum elongation E_0 of specimens quenched and tempered at 400° C. expressed in terms of composition are also given in Table I, the standard error being 2·03%.

From the equations for log a and log b and the data in Table I, the parameters a and b of the locus of the tensile-elongation relation of any steel may be calculated from its composition and its equation expressed in the form

$$E = a\ (b - T)$$

From the data in Table I the minimum and maximum elongations and the minimum and maximum tensile strengths can also be calculated, giving a complete knowledge of the obtainable properties within the limits of heat-treatment experimented with.

From *Metals Technology*, 1940, Vol. 11, No. 5, and *A.I.M.M.E. Technical Publication*, No. 1719, 13 pages.

From the tests carried out an entirely satisfactory understanding of yield strength (yield points) could not be established. It was found, however, that within the range investigated all the wheels had either a yield point or yield strength which depended upon the type of heat-treatment and hence, to some extent, but not completely, on the Brinell hardness. The transition value of this property when a change is made from one type of plastic deformation to another was not perfectly sharp and apparently had some relation to composition. The yield ratio of a steel, therefore, is apparently determined much more by the type of heat-treatment than by the composition, and is but little affected whether there is a yield strength or a yield point.

In general the various tests have shown that within the limits of heat-treatment and composition dealt with, the combinations of tensile strength and elongation obtainable from a given steel by variations in heat-treatment fall upon a straight line whose length, position and direction can be calculated with considerable accuracy from the chemical composition. It has also been shown that a similar relationship exists regarding Brinell hardness and tensile strength. Reasons have also been given for believing that the yield ratio of a steel can be expressed in terms of its heat-treatment and hardenability and that a similar relationship may be found regarding the ratio of elongation to reduction of area.

The Technical Cohesive Strength of some Steels and Light Alloys at Low Temperatures

By D. J. McAdam, R. W. Mebs and G. W. Geil

IN two recent papers[1, 2] two of the authors have presented data obtained in their own experiments, which involved tension tests of notched specimens and based on that data have discussed the technical cohesive strength. The metals dealt with in those papers had high ductility when tested at room temperature. The present paper gives results obtained with less ductile metals, including high-carbon steels and light alloys, and also gives additional results obtained with one of the previously discussed metals (13% chromium, 2% nickel steel). Because of the lesser ductility it was found necessary to include experiments with notch-root radii larger than those used previously and to make a more thorough study of the root radius on the strength and ductility of notched specimens.

The alloys used were a 0·73% carbon steel, a steel containing 13% chromium, 2% nickel, duralumin as aged, containing 4·5% copper, 1·5% magnesium and 0·6% manganese, and three extruded magnesium alloys. The chromium-nickel steel was tested after furnace cooling from 670° C., and the 0·73% carbon steel both in the fully annealed condition, 785° C. cooled in furnace, and after quenching in oil from 785° C. and tempering at 540° C.

To study the influence of plastic deformation on the technical cohesive strength and to reveal more clearly the influence of the radial stress ratio on the technical cohesive limit, some specimens of duralumin and the magnesium alloys were investigated in the usual commercial condition and after being cold drawn 13% reduction in cross section.

From the results obtained curves are given showing the variations of the yield stress, ultimate stress, breaking stress and ductility with the notch angle. Comparison of these curves reveal qualitatively the influence of notch depth and root radius. The tests carried out on the two steels at room temperature showed that the chromium-nickel steel was sufficiently ductile to permit the tensile load to reach a maximum with deeply notched specimens even when the root radius was only a 0·001 in. With deeply notched specimens the influence of stress concentration was minimised and the elevating influence of the increasing radial stress ratio was dominant, while with shadow notched specimens the depressing influence of stress concentration eventually predominated. The radial stress ratio tended to increase with decrease in root radius.

The 0·73% carbon steel was found not to be sufficiently ductile to permit the tensile strength to reach a maximum when the notch angle and root radius were less than certain values which depended on the notch depth. With root radius 0·01 in. fracture was premature when the notch angle was 120° or less and with root radius 0·03 in. fracture was premature when the notch angle was 90° or less. With root radius 0·08 in. fracture was not premature. The height reached by the curve of ultimate stress was also found to be greatest when the root radius was 0·03 in., was slightly less when the radius was 0·05 in., was considerably less when the radius was 0·01 in., and was much less when the radius was 0·08 in. The radius that gave the highest value of the ultimate stress varied with the ductility of the metal and was greater for the 0·73% carbon steel than for the more ductile chromium-nickel-steel.

For a satisfactory study of the technical cohesive strength of a metal, consideration must be given to prior plastic deformation. Experiments were therefore made with duralumin as received (heat-treated) and after cold-drawing to about 13% reduction. The alloy in each state was tested at room temperature, at 78° C. and at — 188° C. With the "as received" alloy, fracture was premature when the notch angle was 120° or less and with the cold-drawn metal when the angle was 90° or less. The tendency to premature fracture was slightly increased when the temperature was lowered from room temperature to 78° C., but was greatly increased when the temperature was lowered to — 188° C. With cold-drawn metal at — 188° C., fracture was premature when the notch angle was 150° or less. The curves of ultimate stress reached the greatest height when the root radius was 0·03 in., the height obtained was a little less when the radius was 0·05 in., and was considerably less when the radius was either 0·08 or 0·01 in. The greatest value of yield stress at room temperature was reached with root radius 0·01 in.

Experiments with magnesium alloys were made with the notched specimens of an alloy as received and after cold-drawing to about 13%. At 78° C. and 188° C., the ductility of the magnesium alloy was decreased so much that satisfactory diagrams of technical cohesive strength could not be obtained. At 78° C., fracture was premature when the notch angle was 120° or less, and at 188° C., the breaking stresses were lower for specimens with notch angles 120° and 90° than for an unnotched specimen. For the alloy as received

1. METALLURGIA, 1944, Vol. 30, pp. 58–60.
2. METALLURGIA, 1944, Vol. 31, pp. 106–107.

the high curve of ultimate stress was obtained with a root radius 0·05 in. The radius that gave the best results therefore was larger for these alloys than for steels or duralumin. Although little tendency was shown at room temperature to premature fracture, evidence obtained indicated that important stress concentration was present at maximum load and at fracture.

Supplementary experiments were made with unnotched specimens of duralumin and a magnesium alloy at additional temperatures ranging between 100° C. and 180° C., to study the quantitative variation of strength with temperature. The results of these tests together with results obtained previously at room temperature showed that a linear relationship was not obtained with duralumin and magnesium alloys even between −188° C. and −78 ° C., as was obtained with nickel and high-purity aluminium. These departures from linear relationship were considered to be due to some structural changes, which vary with the temperature.

From *Amer. Soc. for Testing Materials*, June, 1944. Preprint No. 27. 31 pages.

Mutual Influence of Electrodes and its Importance for Corrosion

G. V. Akimov

CONSIDER four electrodes immersed in an electrolytic solution, the conductance of which is so high that the electrode potentials are determined by the polarisation only. In Fig. 1 the potentials of these electrodes (ϵ_1, ϵ_2, ϵ_3 and ϵ_4) are shown as functions of the polarising current strength I (not current density); for clarity the relation between ϵ and I is assumed to be linear. If the direction of these lines is known, the intensity and direction of the currents flowing, in a steady state, between the electrodes can be ascertained. For that purpose all the cathodic currents are summed, and so are all the anodic currents; the potential at which these currents are equal represents the common potential of all the four electrodes in steady state (the Ohmic drop of potential being neglected). To simplify Fig. 1 the curves for anodic polarisation of the electrodes 1 and 2, and those for cathodic polarisation of the electrodes 3 and 4 are not shown; the electrodes 1 and 2 are cathodes and 3 and 4 are anodes. The line cc is the sum of the cathodic, and the line aa, the sum of the anodic currents; and the common potential is equal to ϵ_0.

If the polarisation of a cathode is reduced, i.e., if the ϵ–I line of a cathode is nearer to the horizontal, the common potential ϵ_0 is lower; if it is lower than ϵ_2, i.e., the potential of the electrode 2 in absence of polarisation, this electrode will be an anode instead of being a cathode as in Fig. 1. That means that the weaker is the cathodic polarisation, the more electrodes function as anodes. The cathodic polarisation can be reduced, e.g., by (1) introducing oxidising agents into the solution, (2) increasing the area of the main cathode, or (3) raising the external resistance between the main anode and the main cathode.

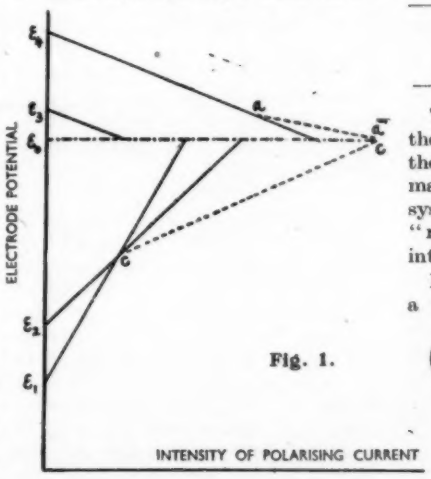


Fig. 1.

In the following tables examples of these effects are given. In the experiments reported in Table I, 5 electrodes were connected by metal wires to one central point (star wiring), and the intensity of the current flowing in every wire was measured; it is given a minus sign when the electrode was an anode, and a plus sign when it was a cathode. It is seen that gradual addition of hydrogen peroxide makes first aluminium and then also cadmium to an anode.

TABLE I.

H_2O_2 (%)	Current strength (milliamp)				
	Zn	Al	Cd	Pb	Pt
0	− 0,35	+ 0·03	+ 0·06	+ 0·07	+ 0·19
0·05	− 8·16	+ 0·16	+ 2·28	+ 2·88	+ 2·84
0·1	−14·0	+ 0·04	+ 3·54	+ 5·30	+ 4·92
0·3	−36·8	− 5·4	+ 5·6	+ 9·6	+27·0
0·5	−40·4	−17·0	+ 3·0	+ 4·4	+50·0
1·0	−47·6	−33·2	− 8·6	+ 2·4	+87·0
1·5	−44,0	−34·6	−19·0	+ 1·6	+96·0

Table II refers to a four-electrode system, in which the area of the most cathodic electrode was gradually increased; this transformed first aluminium and then also cadmium into anodes.

TABLE II.

Area of the Cu. electrode (sq. c.m)	Current strength (milliamp)			
	Zn	Al	Cd	Cu
8	−1·00	+0·012	+0·062	+0·96
40	−2·90	+0·005	+0·050	+2·86
200	−4·88	±0·000	+0·008	+4·90
500	−7·25	−0·028	−0·020	+7·20

TABLE III.

Current strength in the cadmium branch (milliamp)

In 0·1 N HCl		In 3% NaCl solution.	
Resistance of the Pt–Zn connection (ohms)	Current strength	Resistance of the Pt–Zn connection (ohms)	Current strength
420	+0·119	2000	+0·079
600	+0·075	4000	+0·046
800	+0·035	6000	+0·024
1400	−0·009	8000	±0·000
2200	−0·030	10000	−0·012

Table III shows that an increase of the resistance of the wire connecting the main cathode (platinum) to the main anode (zinc) of a three-electrode system Zn-Cd-Pt can transform the "middle" electrode from a cathode into an anode.

If into the system shown in Fig. 1 a fifth electrode is introduced the potential of which in absence of polarisation is more cathodic than any of the previous electrodes (i.e., lies below ϵ_1), then the resulting curve of the total cathodic current will be situated lower than the curve cc and will cross the curve of the total anodic current below the level of ϵ_0; it may lower the level of the common potential so much that the electrode 2 will become an anode (i.e., the new common potential will be between ϵ_1 and ϵ_2). Table IV shows this effect: In a system of Al and Cd cadmium is cathode; if Pb is introduced, cadmium becomes an anode; if Zn is introduced into the Al-Cd-Pb system both

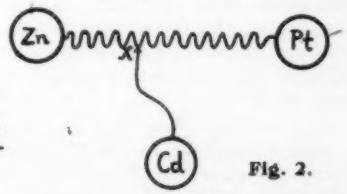


Fig. 2.

From *Uspekhi Khimii*, 1943, **12** 374.

TABLE IV.

Current strength (milliamp.).

Electrodes present	Zn	Al	Cd	Pb	Pt
Al, Cd ..	—	−0·021	+0·021	—	—
Al, Cd, Pb	—	−0·034	−0·20	+0·054	—
Zn, Al, Cd Pb ..	−0·184	+0·036	+0·010	+0·078	—
Zn, Al, Cd Pb, Pt	−0·268	+0·016	+0·018	+0·074	+0·160

cadmium and aluminium become cathodic, but are less cathodic if now Pt (a very strong cathode) is added.

If in the Zn-Cd-Pt system the resistance between zinc and platinum is kept constant but the junction (see point X in Fig. 2) between this resistance and the wire leading to Cd is moved, the current in this wire (the resistance of which is kept small) varies as shown in Table V; the larger is the ratio of the resistance of the anodic (adjacent to zinc) to that of the cathodic (adjacent to platinum) portion, the more anodic is the "middle" electrode.

TABLE V.

Current strength in the cadmium branch (milliamp.).

Resistance (ohms) of the Anodic branch	Cathodic branch	Current strength
0	1000	+0·12
300	700	+0·07
380	620	±0·00
100	600	−0·03
500	500	−0·20
800	200	−1·08

In this example the behaviour of the "middle" electrode is determined by the external resistances directly, not by the polarisation as influenced by the external resistances. It is easily shown that, if in a "star connection" between several electrodes the conductances of the connecting wires are λ_1, λ_2, etc. and the potential of the non-polarised electrodes are ϵ_1, ϵ_2, etc., then the potential ϵ_0 of the star centre (X in Fig. 2) is equal to

$$\frac{\epsilon_1\lambda_1+\epsilon_2\lambda_2+\ldots}{\lambda_1+\lambda_2+\ldots}$$

if ϵ_1 is more positive (more noble) than ϵ_0, it will be a cathode; otherwise an anode.

If the electrodes are connected in a series, the equations for their potentials are more complicated and are not reproduced here.

The general principles expostulated above may be illustrated by two examples of corrosion and of protection against it.

(1) In some heat-treated aluminium-copper alloys the grain boundaries consisting manly of aluminium which has dissolved only about 0·3% of copper; nearer to the centre of the grain there is a layer of this solid solution mottled by inclusions of the compound $CuAl_2$, and the central part of the grain consists of a solid solution of Al 96, Cu 4%. In this system the small anode along the grain boundary is opposed by two cathodes, a small but very actibe $CuAl_2$ and a large but weak solid solution Al 96, Cu 4%; that results in a troublesome corrosion between grains. To prevent it, a strong anode (zinc or aluminium) is introduced; that lowers the value of the common potential (see Fig. 1) so much that the phase Al 99·7, Cu 0·3% becomes an anode or a very weak cathode. Or some magnesium is added to the Al-Cu alloy; that makes the whole grain an anode, leaving only $CuAl_2$ inclusions to function as cathodes; their area is small, hence the polarisation is large and the total corrosion is small.

(2) Heating of chromium steels (and some chromium-nickel steels) leads to formation of inclusions of chronium carbide plus iron carbide. They are strongly cathodic; the Fe-Cr phase near the grain boundary, which has lost some chromium to the carbide phase, is strongly anodic, and the unchanged Fe-Cr grain (containing over 10% of chromium) is a weak but a very large cathode. Consequently, the grain boundary is corroded. To stop the corrosion strong carbide-formers (Ta, Nb, Tl) are added to the steel. They prevent a formation of Cr carbides and make the system one of two electrodes, viz., Fe-Cr phase and carbide phase (Tl, Nb, and Ta carbides). Even if the carbide phase is a cathode, the anode will not be corroded much as the total area of the cathodes is very small.

The Degassing of Light Metal Alloys by Sonic Vibrations

By W. Esmarch, T. Rommel and K. Benther

IT is well known that the passage of an ultra sonic wave is accompanied by the formation of gas bubbles. These bubbles are partly due to the coalescence of microscopic bubbles already present in the liquid and are reinforced by previously dissolved gas being liberated in the low-pressure regions of the sound wave.

Kruger, in 1931, took out a patent for degassing metallic melts by this method (German Patent No. 604486), ultra sonic waves being generated in the melt by a dipper controlled by a magnetostrictive oscillator. The main difficulty in this process was the provision of suitable material for the dipper. Ceramic materials rapidly disintegrated whilst metallic dippers only proved suitable in rare instances. In addition, the process of wave generation in the melt is very inefficient, a considerable proportion of the energy of the oscillator being lost by reflexion at the surfaces of separation or absorbed by the dipper.

It appears that the only way of making the process commercially possible would be the generation of high-frequency waves directly inside the melt. Now in the high-frequency electric furnace, the heat production is due to the formation of eddy currents in the charge. These eddy currents, moreover, are subjected to electrodynamic forces due to the magnetic field of the furnace circuit and cause the well-known rotary motion of the melt in induction furnaces.

This rotary motion favours the absorption of air by the molten materials and therefore counteracts to some extent the degassing effect of the rise in temperature.

By superimposing a steady magnetic field on the high frequency field of the furnace (the resultant field being in the direction of the coil axis), mechanical vibrations can be induced in the melt, the force at each point being proportional to the product of the local current density and field strength and acting radially to the coil axis. Moreover, by suitable choice of bath dimensions, resonance effects can be produced which increase the intensity of the vibrations. We thus have a method of generating high-frequency waves in the melt without the need of a dipper. On the other hand, the frequency range is restricted to that of the alternating current feeding the furnace.

The authors are, however, convinced from preliminary experiments that there is no advantage from the degassing point of view of employing frequencies in excess of 10,000/sec., provided that the intensity of the vibration is sufficient.

From *W. V. Siemens Werke, Werkstoff Sonderheft*, Berlin 1940, pp. 78–87. Courtesy of R.T.P.3, Ministry of Aircraft Production.

In their experiments, therefore, an A.C. generator of this frequency was employed for feeding the furnace coil, the average current consumption being of the order of 100A. The superimposed steady magnetic field was produced by 450 direct currents fed with the same coil, the D.C. generator being protected by the insertion of suitable chokes and condensers. The total energy consumption amounted to about 15 kw. of which 10 kw. were supplied by the high-frequency generator. The high D.C. wattage is largely due to the fact that a standard furnace was employed. With a specially designed heating coil, the energy consumption for the steady magnetic field could have been reduced very considerably.

The experiments were carried out with 8–10 kg. melts of pure aluminium and aluminium-magnesium alloys, the temperature being kept constant at 700° C. Samples were drawn off every 10 minutes and the gas content determined by the well-known vacuum method. Photographs were also taken of the polished sections.

It appears that alloys containing a relatively large percentage of Mg. can be completely degassed by this method, in 30–60 minutes, provided the surface of the melt is protected by a fused salt layer and that dry air or nitrogen is directed on to the surface during the treatment.

Suitable salts can be obtained from the I.G. under the trade names, Hydrosal and Elrasal. A laboratory product utilised by the authors and giving equally good results has the following composition :—

K Cl	..	40%
Na Cl	..	30%
$Ca CO_3$	..	15%
Naf	..	15%

Chemical and Mechanical Properties of some of the National Emergency Steels

By W. C. Stewart and R. E. Wiley

THE primary purpose of the investigation was to obtain information as to the strength properties of these steels in large sizes, although smaller diameter bars were also included, as large forgings are required for propulsion shafting and rudder stocks which must conform to the physical properties of Classes AN and HG steels of Navy Department specification 49 S 2, Table I. In all, 36 steels, representing 10 grades, were investigated in sizes ranging from 1 in. to 14 in. diameter. These grades included N.E. steels, 8749, 8949, 9739, 9445, 9450, 8630, 8739, 8339, 8744 and 8442. Similar steels obtained from different sources were tested in order to determine the effect of manufacturing in large section and because of their inherent hardenability, normalising and tempering heat-treatments were given preference over quenching and tempering procedures, the forgings being normalised in full section and tempered in as large sections as practicable.

The tests included the determination of static and torsional properties, Charpy impact value, hardness, and fatigue resistance in rotating flexure and alternating torsion. The hardenability was determined by means of the end-quenched test. Temperature-expansion (dilatometric) curves were obtained for representative steels. In determining these properties the location of specimens with reference to the cross section of the forging was considered. In addition, the high temperature characteristics of some of the steels were determined. The chemical composition of all the steels were determined and in a considerable number of cases failed to conform to the specified analysis in one or more elements.

The results obtained show that the National Emergency Steel of the 8000 series can be used as alternate material for forgings to meet the Navy Department Specification 49 S2. Of the seven steels of this series, one is of the semi-thorough-hardening grade (N.E. 8630) and the others of the thorough hardening grade. All have shown to good advantage when properly heat-treated. Of the less hardenable steels, N.E. 8739 is a good representative material, while of the steels of greater hardenability, N.E. 8749 has shown good properties. These steels are found to be well adapted for heat-treatment by normalising and tempering at 650° to 700° C. This procedure is desirable for large sections and the tempering temperature is not critical, but becomes so after oil quenching. Steels N.E. 9945 and 9450 were less satisfactory and failed to meet the specification. The former, however, met the AN requirements after normalising and tempering at 700° C., while the latter failed to meet either AN or HG requirements after normalising and tempering at 650° and 700° C.

The average endurance limit for the 20 steels tested in rotating flexure was 0·43. This was somewhat lower than would be expected for alloy steels and in this respect the steels are intermediate between carbon and alloy steels. In regard to similar ratios for endurance in alternating torsion, these were not appreciably different from those of alloy steels. N.E. steels of this series were found to be inferior to available high-temperature bolting materials where the high-temperature strength depends on molybdenum or tungsten. The N.E. steels contain no tungsten and the molybdenum content is not sufficiently high for the necessary strength at elevated temperatures.

From *Jour. Amer. Soc. Naval Eng.*, 1944. Vol. 56 No. 3, pp. 396–409.

TABLE I.—NAVY DEPARTMENT SPECIFICATION 49 S2.

Class	Tensile Strength Minimum	Proof Stress Minimum	Elong. on 2 in. Min.		Red. of Area Min.	
			Longitude	Transverse	Longitude	Transverse
	P.S.I.	P.S.I.	%	%	%	%
A.N. ..	80,000	45,000	25	21	45	30
H.G. ..	95,000	65 000	21	18	45	30

Electronic Devices in Metallurgy

ELECTRONIC developments have made an invaluable contribution to metallurgical research, improving old methods and opening new avenues of approach. The U.S. Bureau of Mines has published a report on use of electrical devices in metallurgical research. Physical metallurgy is a field in which the Bureau has found electronic devices particularly useful, according to physicist E. V. Potter, of the Salt Lake City Experiment Station, author of the paper. He particularly describes the more special and unusual applications in physical metallurgy. However, the Bureau has done metallurgical research involving electronic devices in ore dressing, hydrometal-

lurgy, pyrometallurgy, and electrometallurgy, and there are a number of instruments which are widely used in these fields. Among them are electrostatic separators, automatic furnace controllers, induction furnaces, rectifiers, microscopes, and X-ray diffraction units. In associated chemical work such apparatus as titrimeters, conductivity bridges, colorimeters, and polarographs employing electron tubes, are used.

U.S. Bureau of Mines Information Service, June 28 1944.

Simplification of Design for Production. The Avoidance of Unnecessary Refinements

By P. Leinweber

AN efficient engineering product should satisfy the requirement for which it has been produced but all refinements in excess of these should be rigidly excluded. In the case of a watch, for example, the expensive chronometer escapement is only justified in special cases. On the other hand high quality springs should always be fitted. Turning the watch into a piece of jewellery is a departure from efficient design and only justifiable under peacetime conditions. The same applies to the keyless winding mechanism. It is expensive to produce and facilitates the entry of dust. As soon as standardised keys become available, the winding operation can be carried out almost as simply, with a considerable saving in materials and cost of manufacture. These remarks apply with special force to war materials, which in many cases still incorporate unnecessary refinements. As an example, the author instances the standard German machine-gun holding bracket which formerly was provided with an expensive ratchet giving adjustment of a few centimetres by means of a handwheel. This adjustment was rarely used and has now been done away with, thus simplifying the bracket considerably. According to the author, the Soviet military authorities have gone far in simplifying their military equipment in this way without sacrificing striking power.

There are six main headings under which new designs should be examined to ensure that utmost simplification has been achieved.

1. Limitation of requirements to be met by the finished article to bare necessities.

2. Reduction of accuracy and manufacturing limits consistent with facility of replacement.

3. Limitation of surface finish to those parts where high finish or special surface qualities (hardness) are essential. This also applies to anti-corrosion treatment.

4. Limitation of types and far reaching standardisation of parts.

5. Avoidance of bottle necks due to specification of materials in short supply or difficult methods of manufacture.

All these points should be borne in mind before the design is actually undertaken and not left till a prototype has been constructed. Close co-operation with specialists is indicated, especially as regards items (4) and (5).

Once an article has gone into wide production, simplification is often difficult to achieve. In this case the advantages due to a saving in material and labour must be carefully weighed up in comparison with a closing up of production during the change-over period. Nevertheless, the difficulties under which German industry has to operate under present conditions make it urgent that simplifications in the design of products be carried out and the author impresses all engineers with the importance of this problem.

Z VDI, vol. 88 (1944), pp. 121–124. Courtesy of R.T.P.3, Ministry of Aircraft Production.

An Evaluation of Quenching Oils

By E. K. Spring, P. T. Lansdale and C. W. Alexander

A STUDY was made of the quenching rates and physical properties of various commercial quenching oils. The oils chosen for examination were those most commonly used for the quenching of steel, some being animal oils, some mineral oils, and some blended oils.

The oils were evaluated by plotting time-temperature curves for the quenching of a standard block of 18–8 stainless steel. All the oils were tested at a series of initial temperatures, these being 80°, 130°, 220°, 300° and 450° F. Typical time-temperature curves at the various temperatures are those obtained for oil C, and are given in Fig. 1.

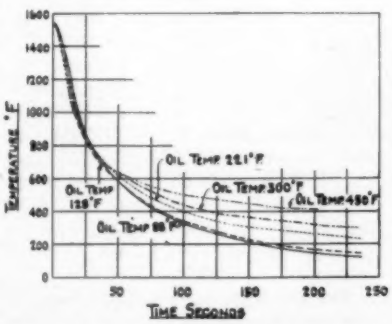


Fig. 1.—Typical time versus temperature curves for oil C.

The data obtained from the various tests showed that there are negligible differences in the quenching rates of new and used oils, and that there is an optimum oil temperature to produce the maximum cooling rates at the nose of the "S curve." Oil temperatures above or below this optimum temperature retard the cooling rate in this important temperature range. Warm oil has the desirable effect of giving slower cooling rates in the region of the martensitic transformation. Similar quenching rates are exhibited by oils of animal and mineral origin, and slight differences in the quenching rates of "light" and "heavy" oils can be compensated for by adjusting the oil temperature.

The greatest variation in quenching rates developed by the oils tested was found to be but a minor factor in the hardenability of steel. The results also showed that all the oils tested were metallurgically equal, and that the selection of a quenching oil should therefore be decided by its flash and fire points, which must be sufficiently high to prevent undue damage from fire, and by its cost per pound of steel quenched under normal operating conditions.

From *Trans. Amer. Soc. for Metals*, 1944, vol. 33, pp. 42–55.

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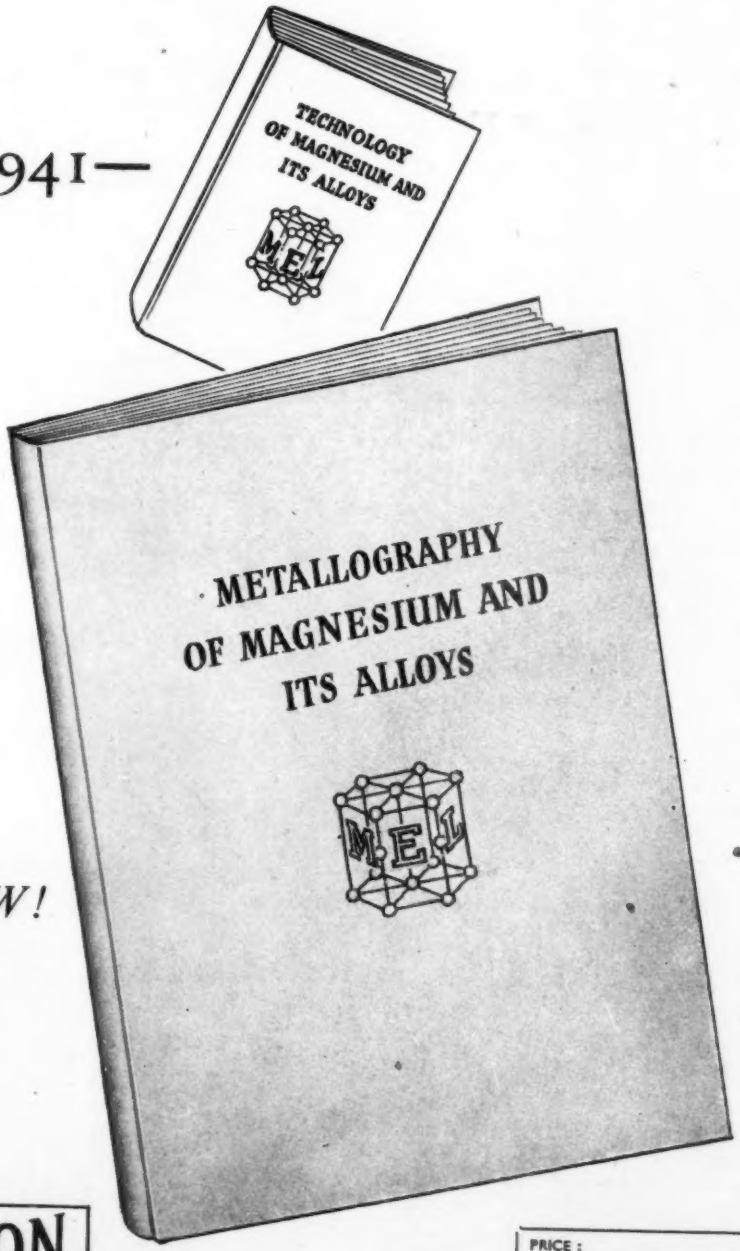

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Fatigue Testing Machine for Aircraft Structural Elements

THE testing machine forming the subject of this patent is characterised by its compactness and light weight and is thus specially suited for attachment to aircraft elements which normally are difficult of access. The machine is essentially a Vibrator, characterised by the fact that the stress amplitude is maintained constant during the test irrespective of the deflection of the specimen. For this purpose an opposed piston aggregate consisting of two open-ended cylinders and a straight-through connecting rod is employed. The pistons are caused to oscillate by air pressure and the resultant vibratory motion is transferred to the specimen under test by attaching one end of the latter to the connecting rod in question whilst the other end is rigidly held.

The special feature of the machine is the fact that the working cylinders are not rigidly fixed to a base plate but are free to slide under the control of elastic abutments attached to the closed ends. Confining our attention to one of the piston cylinder units, it is clear that on the admission of compressed air to the cylinder, the piston and cylinder will move in opposite directions, the respective travel depending on the resistance offered by the test specimen (attached to the connecting rod) and the cylinder abutment. Moreover, for a given spring characteristic of the latter, the position of the cylinder corresponding to a given stress in the specimen is fixed. As soon as this position is reached, the cylinder operates a suitable valve mechanism which releases the air pressure and at the same time allows compressed air to enter the second working cylinder which up to then was at atmospheric pressure. The cycle is then repeated, specimen being strained in the opposite direction. In this manner the specimen is automatically subjected to cyclic stresses of constant amplitude irrespective of the actual piston travel or strain amplitude of the test specimen.

Moreover, for a given abutment elasticity, the frequency of the stress cycle can be varied over wide limits by simply altering the air pressure fed into the system.

Junkers aircraft German Patent No. 744942. Courtesy of B.T.P.3, Ministry of Aircraft Production.

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